AD NUMBER
ADB042565
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; OCT 1979. Other requests shall be referred to Commander, Army Armament Research and Development Command, ATTN: DRDAR-TSS, Dover, NJ 07801.**
AUTHORITY
ARRADCOM ltr dtd 10 Apr 1984

AD

AD-E400 374

TECHNICAL REPORT ARLCD-TR-79019

DERIVATION OF THE KINEMATIC PROPERTIES OF THE PIN PALLET RUNAWAY ESCAPEMENT

C. W. JANOW
F. R. TEPPER

OCTOBER 1979

U.S. ARMY ARRADCOM

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

THIS REPORT HAS BEEN DELIMITED AND CLEARED FOR PUBLIC RELEASE UNDER DOD DIRECTIVE 5200.20 AND NO RESTRICTIONS ARE IMPOSED UPON ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report ARLCD-TR-79019	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): DERIVATION OF THE KINEMATIC PROPERTIES OF THE PIN PALLET RUNAWAY ESCAPEMENT	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): C. W. Janow F. R. Tepper	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: ARRADCOM, LCWSL Nuclear and Fuze Division, DRDAR-LCN-C Dover, NJ 07801	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: ARRADCOM, TSD STINFO, DRDAR-TSS Dover, NJ 07801	12. REPORT DATE: October 1979
	13. NUMBER OF PAGES: 72
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government agencies only because of test and evaluation, October 1979. Other requests for this document must be referred to the Commander, ARRADCOM, ATTN: DRDAR-TSS, Dover, NJ 07801.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Runaway escapement	Safing and arming	Mechanism analysis
Pin pallet	Velocity ratio	Entrance cycle
Kinematic properties	Torque transfer ratio	Exit cycle
Rdvspr ehrrl	Efficiency	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The operation of the pin pallet runaway escapement has been characterized in terms of several kinematic properties, i.e., velocity ratio, torque transfer ratio, and efficiency. A computer program has been written which analyzes both the entrance and exit phases of the engagement cycle. The influence of changes in the operating center distance has also been investigated by appropriate computer runs. As a result of this study, an analytic tool for the evaluation of the performance of proposed pin pallet escapement designs or for the modification of existing mechanisms is now available.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

This report is the first in a series of reports documenting analytical efforts undertaken as part of the Standard S&A Program. Other reports to follow will deal with the plate pallet, the involute gear mesh, and the clock tooth gear mesh, as well as the entire S&A mechanism.

TABLE OF CONTENTS

TABLE

FIGURES

INTRODUCTION

The pin pallet escapement is commonly employed in fuze safing and arming devices to provide a safe separation distance for arming. This report describes the results of an analytic investigation undertaken to characterize the performance of this type of escapement. The analysis is static in that it is based on the kinematics of the escapement and does not take into consideration the forces acting on the device. However, the analysis provides a useful tool for obtaining information to insure that the escapement will start, and that the motion during engagement of the components will be smooth and continuous.

DESCRIPTION OF OPERATION OF PIN PALLET ESCAPEMENT

A schematic diagram of a typical pin pallet is presented in figure 1. As shown, this escapement consists of two elements. One of these is the pallet, which has two pins attached to it. These pins alternately make contact with the faces of the second element, the escape wheel. The escape wheel is usually connected by a step-up gear train to the element in the fuze system whose motion must be retarded.

The principle of operation of the pin pallet escapement is as follows: Torque is applied to the component to be retarded by the spin of the projectile for an artillery fuze, or by a spring or shell acceleration for other fuzes. This torque is transmitted through the gear train to the escape wheel. As a result of this, the escape wheel will start to rotate and cause the engaging pallet pin to slide up the face of the escape wheel tooth. After the pin has reached the vertex of the tooth, the pallet and escape wheel will move independently. This will continue until the second pallet pin collides with another escape wheel tooth.

The impact theoretically causes the motion of the escape wheel to be instantaneously halted. In actuality, the motion of the escape wheel is usually only slowed, but it is also possible for the escape wheel to momentarily reverse its direction of motion. Of course, whatever motion is experienced by the escape wheel is transmitted back to the element to be retarded through the gear train. In this manner, the required delay is achieved. The step-up gear train is utilized in order to increase the number of impacts between the pallet and escape wheel thereby increasing the number of times the motion of the escape wheel is interrupted.

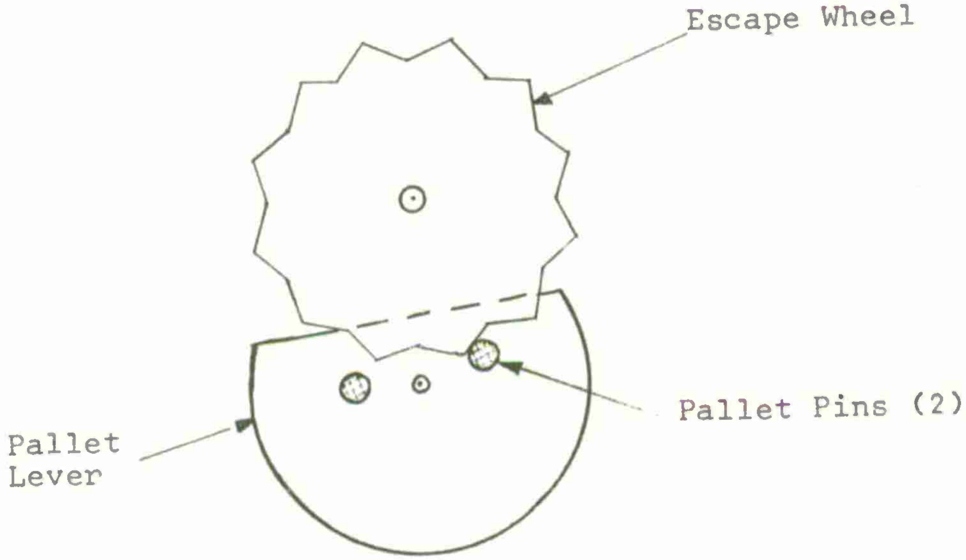

Figure 1. Pin pallet runaway escapement.

ANALYSIS

This section describes the study conducted to characterize the performance of the pin pallet escapement, during the engagement of the pallet and the escape wheel, in terms of its kinematic properties. These include the instantaneous velocity ratio, efficiency and the moment arms of the input and output forces. These parameters furnish the information necessary to determine if an escapement will start and if motion during engagement will be smooth and continuous. Some of the work is excerpted from appendices A, B, and G of reference 1 and is reproduced here, where necessary, for completeness.

Nomenclature

Figure 2 shows the kinematic relationship of the escape wheel and pallet when they are in contact. In this configuration the upper pallet pin (usually referred to as the entrance pallet pin) is being driven by the escape wheel tooth. The following nomenclature is used throughout the remainder of this report:

φ = Escape wheel angle. Defined by the line from the escape wheel pivot Os to the tip of the contacting tooth, and the line connecting Os to the pallet pivot Op.

ψ = Pallet angle. Defined by the line from Op to the active pin center and the centerline.

a = Distance between pivot points Op and Os

b = Escape wheel outer radius

c = Pallet pin radius, to center of pallet pin

r = Pallet pin radius

α = Escape wheel tooth half angle

g = Distance from the contact point to the tip of the escape wheel tooth.

The identical nomenclature will be used for the lower pallet pin (usually referred to as the exit pallet pin).

Kinematics

Determination of ψ and g

Referring to figure 2, the unit vectors $\bar{n}_t$ and $\bar{n}_n$ are defined along and perpendicular to the contact surface of the escape wheel tooth in the indicated direction and are given by:

$$\bar{n}_t = \cos(\varphi-\alpha)\bar{i} + \sin(\varphi-\alpha)\bar{j} \tag{1}$$

$$\bar{n}_n = -\sin(\varphi-\alpha)\bar{i} + \cos(\varphi-\alpha)\bar{j} \tag{2}$$

The unit vectors $\bar{n}_b$ along the line joining the escape wheel center with the tooth tip, and $\bar{n}_c$ along the line connecting the pallet pivot and the pallet pin center, are given by:

$$\bar{n}_b = \cos\varphi\,\bar{i} + \sin\varphi\,\bar{j} \tag{3}$$

$$\bar{n}_c = \cos\psi\,\bar{i} + \sin\psi\,\bar{j} \tag{4}$$

The loop closure equation of this mechanism can be used to determine the pallet angle ψ and the distance g with respect to the tip of the escape wheel as functions of the angle φ.

$$0 = b(\cos\varphi\,\bar{i} + \sin\varphi\,\bar{j}) + g[\cos(\varphi-\alpha)\bar{i} + \sin(\varphi-\alpha)\bar{j}]$$
$$+ r[-\sin(\varphi-\alpha)\bar{i} + \cos(\varphi-\alpha)\bar{j}] - c(\cos\psi\,\bar{i} + \sin\psi\,\bar{j}) + a\,\bar{i}$$

Rewriting the above in component form:

$$b\cos\varphi + g\cos(\varphi-\alpha) - r\sin(\varphi-\alpha) - c\cos\psi + a = 0 \tag{5}$$

$$b\sin\varphi + g\sin(\varphi-\alpha) + r\cos(\varphi-\alpha) - c\sin\psi = 0 \tag{6}$$

The angle ψ is then obtained from:

$$\sin\psi = \frac{[b\sin\varphi + g\sin(\varphi-\alpha) + r\cos(\varphi-\alpha)]}{c} \tag{7}$$

and

$$\cos\psi = \frac{[c^2-(b\sin\varphi + g\sin(\varphi-\alpha) + r\cos(\varphi-\alpha))^2]^{1/2}}{c} \tag{8}$$

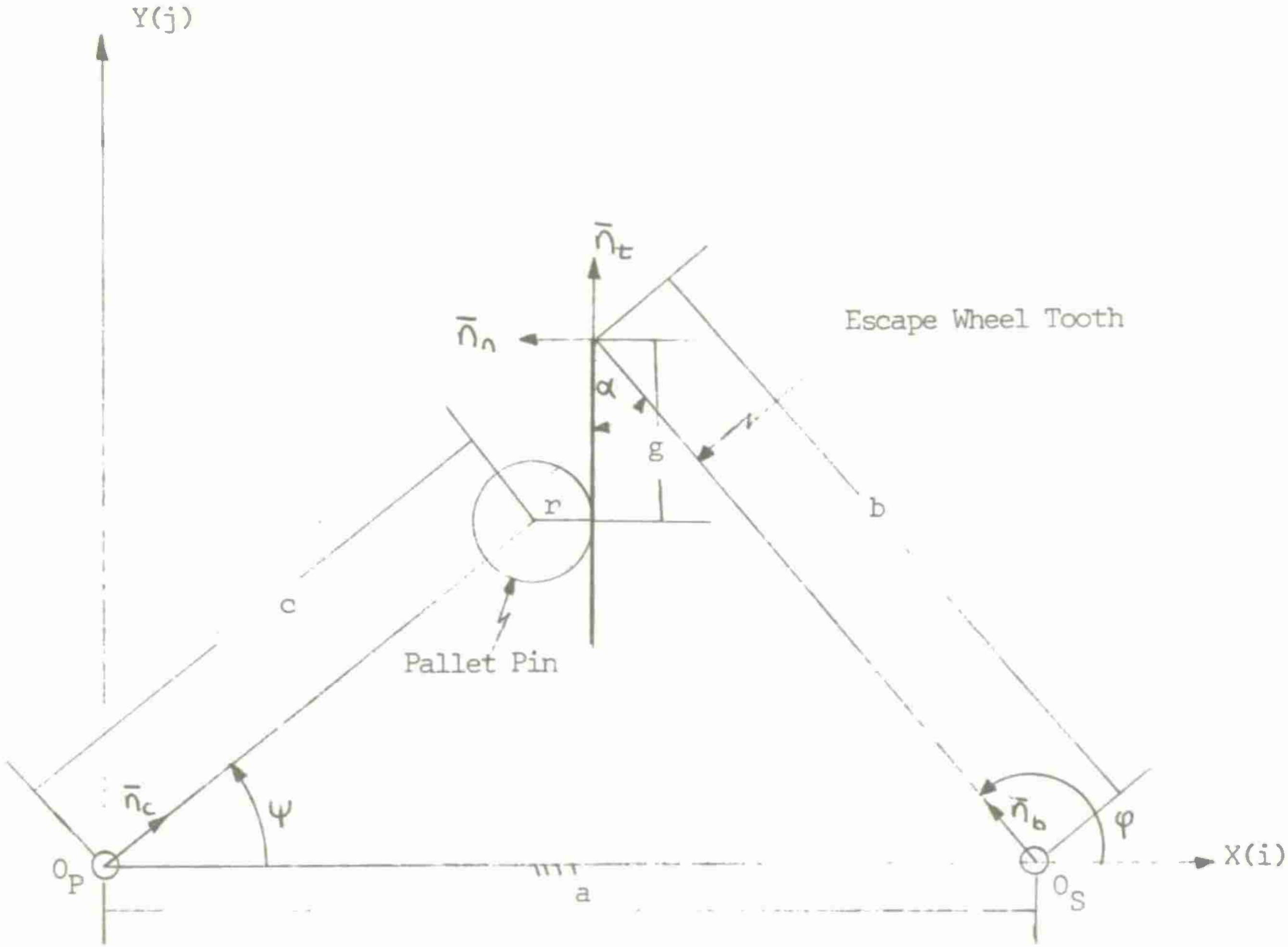

Figure 2. Kinematic relationship coupled motion.

Substituting equation (8) into equation (5) and squaring both sides furnishes

$$[b\cos\varphi+g\cos(\varphi-\alpha)-r\sin(\varphi-\alpha)+a]^2 = c^2-[b\sin\varphi+g\sin(\varphi-\alpha)+r\cos(\varphi-\alpha)]^2$$

Rearranging the above yields:

$$g^2+g[2b\cos\alpha+2a\cos(\varphi-\alpha)]=C^2-b^2-a^2-r^2-2br\sin\alpha-2ba\cos\varphi+2ra\sin(\varphi-\alpha)$$

or

$$g^2+2[b\cos\alpha+a\cos(\varphi-\alpha)]g+b^2+a^2+r^2-c^2+2br\sin\alpha+2ba\cos\varphi-2ra\sin(\varphi-\alpha)=0 \qquad (9)$$

The solution to (9) is given by:

$$g_{1,2} = \frac{-H\pm\sqrt{H^2-4K}}{2} \qquad (10)$$

where

$$H = 2[b\cos\alpha+a\cos(\varphi-\alpha)] \qquad (11)$$

$$K = b^2+a^2+r^2-c^2+2br\sin\alpha+2ba\cos\varphi-2ra\sin(\varphi-\alpha) \qquad (12)$$

The correct value of g must be the one with the smallest absolute value. Thus,

if $|g_1| < |g_2|$ $g = g_1$

otherwise, $g = g_2$

Determination of maximum value of g and corresponding ϕ

At the starting position for either entrance or exit engagement, the pallet pin is located deep in the root between two escape wheel teeth. This location corresponds to the maximum value of g. This value will now be determined with the help of figure 3, which shows the pallet pin at position g = gmax.

From ΔOST the following relationship is obtained:

$$\measuredangle O_sST = \pi-\alpha-\delta/2 \qquad (13)$$

where $\delta = 360/N$

N = number of teeth of the escape wheel.

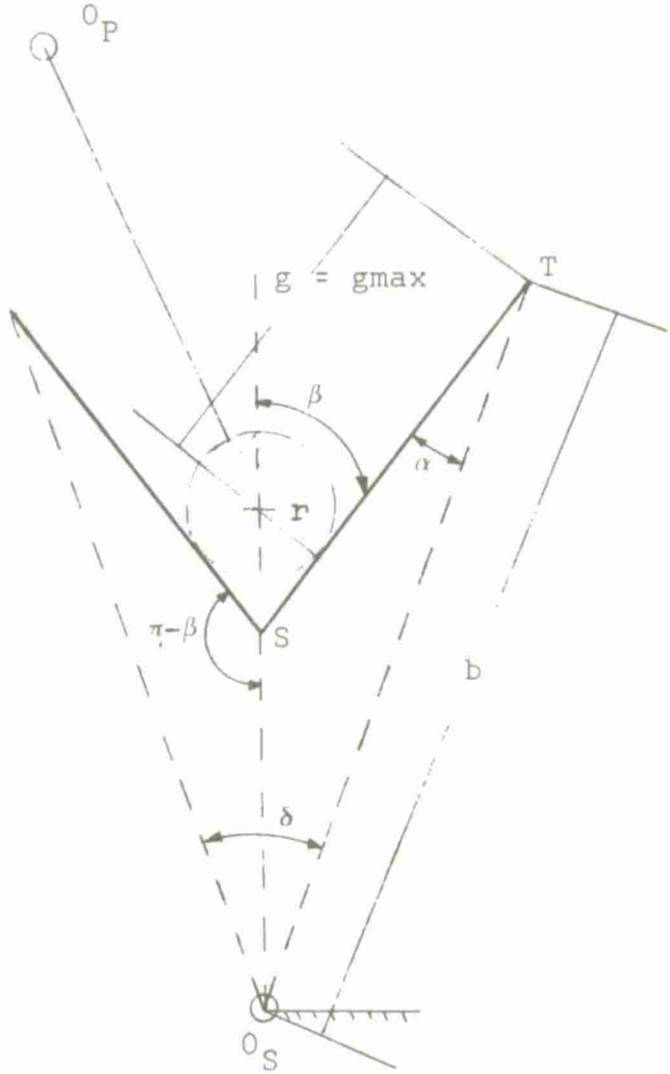

Figure 3. Pallet pin in starting position.

Since $\beta = \alpha+\frac{\delta}{2}$ equation (13) becomes:

$$\measuredangle O_sST = \pi-\beta \tag{14}$$

The distance $\overline{ST}$ of ΔO_sST is determined with the help of the sine law:

$$\overline{ST} = \frac{b\sin(\delta/2)}{\sin(\pi-\beta)} \tag{15}$$

Finally, gmax is given by:

$$gmax = -(ST - \frac{r}{\tan\beta}) \tag{16}$$

Note that in order to conform to the $\overline{n}_t$-$\overline{n}_n$ coordinate system, in which gmax is a negative quantity, a minus sign has been assigned to the above expression.

The angle $\varphi=\varphi_M$ which corresponds to the orientation of the escape wheel when g=gmax is determined from equation (9). With the help of the trigonometric identities for $\cos(\varphi_M-\alpha)$ and $\sin(\varphi_M-\alpha)$ and expressing $\sin\varphi_M$ and $\cos\varphi_M$ in terms of $\tan(\varphi_M/2)$, equation (9) be arranged as:

$$L\sin\varphi_M+M\cos\varphi_M+N = 0 \tag{17}$$

where

$$L = 2a\ [gmax\cdot\sin\alpha-r\cos\alpha]$$

$$M = 2a\ [b+gmax\cdot\cos\alpha+r\sin\alpha]$$

$$N = g^2max+b^2+a^2+r^2-c^2+2b(gmax\cdot\cos\alpha+r\sin\alpha)$$

or

$$\frac{2L\tan(\varphi_{M/2})}{1+\tan^2(\varphi_{M/2})} + \frac{M-M\tan^2(\varphi_{M/2})}{1+\tan^2(\varphi_{M/2})} + N = 0$$

or

$$(N-M)\tan^2(\varphi_{M/2})+2L\tan(\varphi_{M/2})+M+N = 0$$

therefore;

$$\varphi_{M1,2} = 2\tan^{-1}\left[\frac{-L\pm\sqrt{L^2-N^2+M^2}}{N-M}\right] \tag{18}$$

The two solutions correspond to entrance and exit engagement starting positions.

Determination of ϕ for $g = 0$

The angle $\varphi = \varphi_o$, which corresponds to the orientation of the escape wheel when the pallet pin leaves the contacting tooth, may also be obtained from equation (9), by letting $g = 0$:

$$0 = b^2+a^2+r^2-c^2+2br\sin\alpha+2ba\cos\varphi_o-2ra\sin(\varphi_o-\alpha) \tag{19}$$

With similar trigonometric substitutions as those made above, equation (19) may be written as:

$$L_o\sin\varphi_o+M_o\cos\varphi_o+N_o = 0 \tag{20}$$

where:

$$L_o = -2ra\cos\alpha$$
$$M_o = 2a(r\sin\alpha+b)$$
$$N_o = b^2+a^2+r^2-c^2+2br\sin\alpha$$

or

$$\frac{2L_o\tan(\varphi_o/2)}{1+\tan^2(\varphi_o/2)} + \frac{M_o-M_o\tan^2(\varphi_o/2)}{1+\tan^2(\varphi_o/2)} + N_o = 0$$

which can be further reduced to:

$$(N_o-M_o)\tan^2(\varphi_o/2)+2L_o\tan(\varphi_o/2)+M_o+N_o = 0 \tag{21}$$

the solution of which is

$$\varphi_{o_{1,2}} = 2\tan^{-1}\left[\frac{-L_o \pm \sqrt{L_o^{\,2}-N_o^{\,2}+M_o^{\,2}}}{N_o-M_o}\right] \tag{22}$$

As before the two solutions correspond to the entrance and exit engagement loss of contact positions.

Kinematic Properties

Moment Arms

Having obtained both the starting positions and the last positions of coupled motion of the escapement the various kinematic properties of interest may be determined for any position in either entrance or exit engagement.

Figure 4 shows the pin pallet and escape wheel in coupled motion during entrance engagement. In this phase, both the escape wheel and the pallet are rotating in the same direction. The forces between the escape wheel and the pallet pin are represented by the normal force $\overline{P}$ and the friction force $\overline{\mu P}$ acting in the indicated directions.

The moment arms of the forces about the escape wheel center are represented by A_1 and B_1 and are given by:

$$A_1 = b\cos\alpha + g \tag{23}$$

$$B_1 = b\sin\alpha \tag{24}$$

The line 00' represents the line of action of the contacting force P when friction is not taken into account. The introduction of the friction force at the point of contact causes the line of action of the resultant force to be along line 00", which makes an angle ξ with line 00'. This angle is given by:

$$\xi = \tan^{-1}\mu$$

The moment arm A_w of the resultant force may be determined in the following manner. From triangle $0_s00''$ it can be seen that

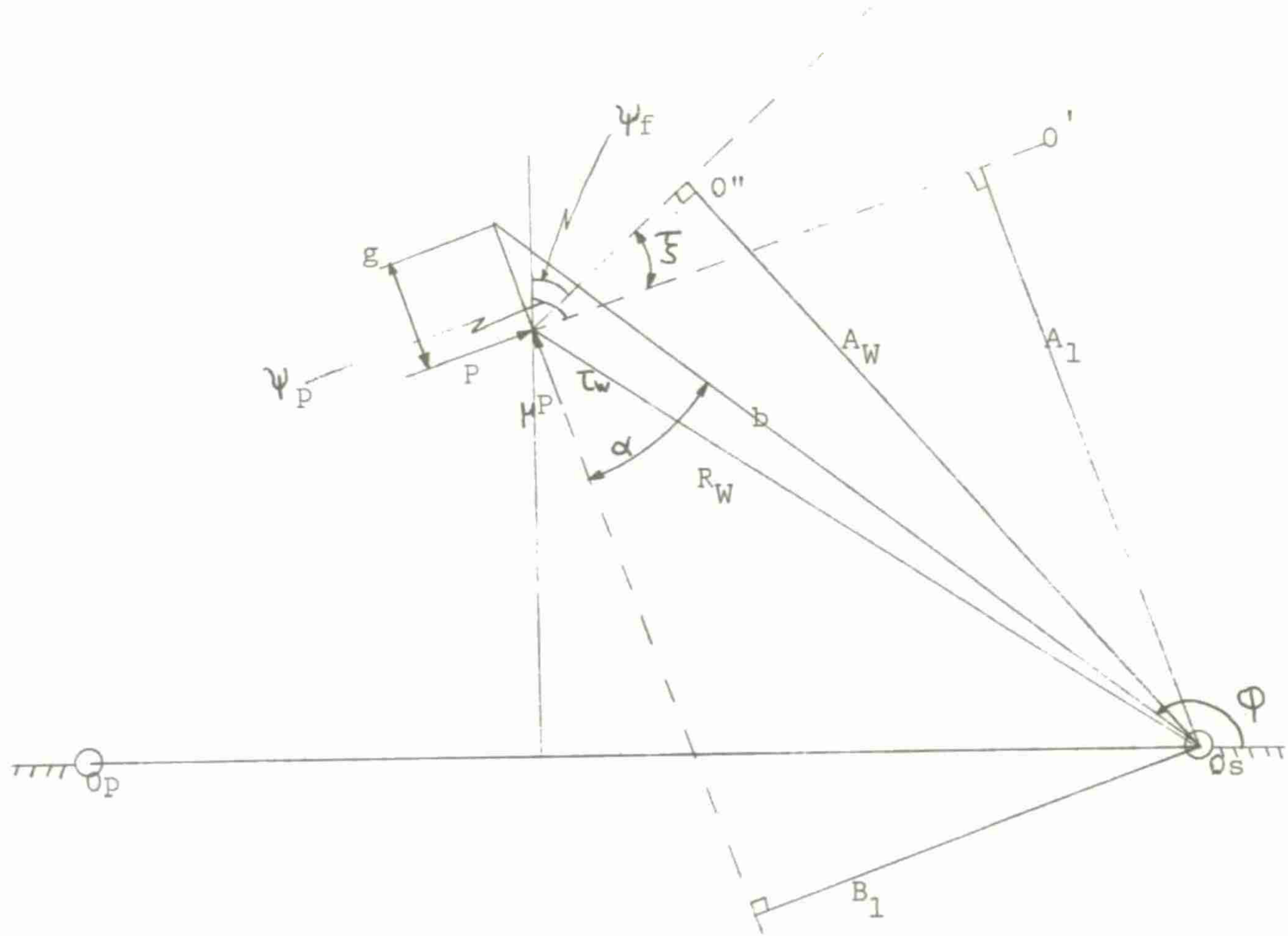

Figure 4. Escape wheel - entrance engagement.

$$R_w = \sqrt{A_1{}^2 + B_1{}^2}$$

$$\measuredangle 0'0_s0 = \tau w = \tan^{-1}\frac{B_1}{A_1}$$

With $\measuredangle 0'0_s0'' = \xi$; $\measuredangle 0''0_s0$ becomes: $\measuredangle 0''0_s0 = \tau w - \xi$

and

$$A_w = R_w \cos(\tau w - \xi) \tag{25}$$

In a manner similar to that for gears, the pressure angle may be defined as the angle that the line of action of the contact force makes with a line which is normal to the centerline at the contacting point. From figure 4, it can be seen that the pressure angle ψ_f can be written as:

$$\psi_f = \pi + \alpha - \varphi \tag{26}$$

When friction is considered, the pressure angle, corrected for friction is given by:

$$\psi_f = \psi_p - \xi \tag{27}$$

Before the kinematics of the pallet may be investigated, expressions for the moment arms of the normal and friction forces acting on the pallet pins must be derived. This will be accomplished with the help of figure 5. This figure shows the moment arms D_1 for the normal force, and C_1 for the friction force, acting on the pallet pin.

The following loop equation is used to obtain C_1 and D_1 (see fig. 5):

$$C\overline{n}_c - r\overline{n}_n - D_1\overline{n}_t + C_1\overline{n}_n = 0 \tag{28}$$

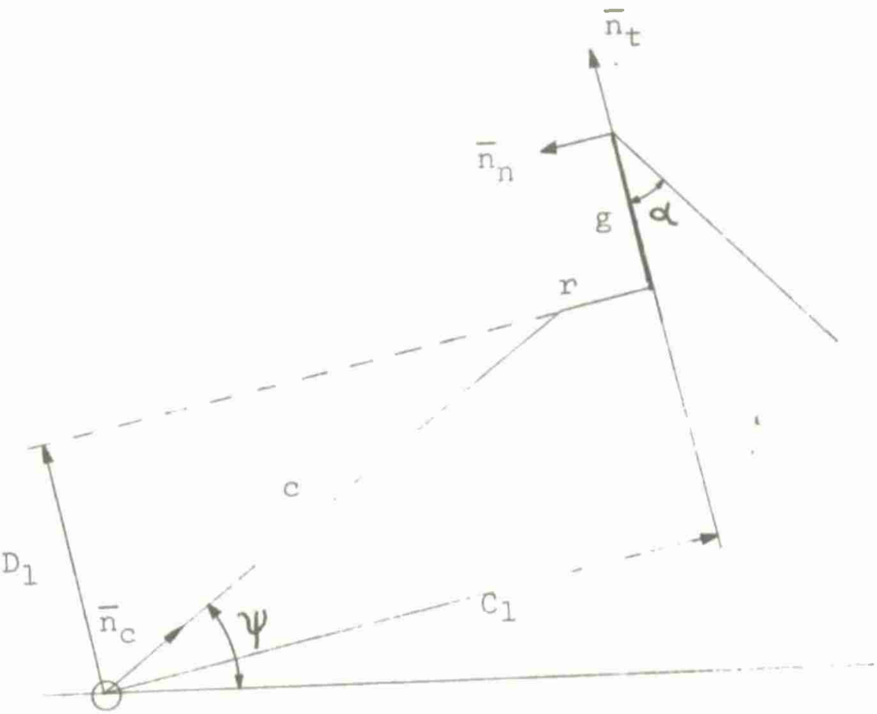

Figure 5. Moment arms about pallet pivot.

Upon substitution of the following

$$\overline{n}_t = \cos(\varphi-\alpha)\overline{i} + \sin(\varphi-\alpha)\overline{j}$$

$$\overline{n}_n = -\sin(\varphi-\alpha)\overline{i} + \cos(\varphi-\alpha)\overline{j}$$

$$\overline{n}_c = \cos\psi\overline{i} + \sin\psi\overline{j}$$

equation (28) becomes:

$$C\cos\psi\overline{i} + C\sin\psi\overline{j} + r\sin(\varphi-\alpha)\overline{i} - r\cos(\varphi-\alpha)\overline{j} - D_1\cos(\varphi-\alpha)\overline{i} \quad (29)$$

$$-D_1\sin(\varphi-\alpha)\overline{j} + C_1\cos(\varphi-\alpha)\overline{j} - C_1\sin(\varphi-\alpha)\overline{i} = 0$$

or, separating into components:

$$C\cos\psi + r\sin(\varphi-\alpha) - D_1\cos(\varphi-\alpha) - C_1\sin(\varphi-\alpha) = 0$$

$$C\sin\psi - r\cos(\varphi-\alpha) - D_1\sin(\varphi-\alpha) + C_1\cos(\varphi-\alpha) = 0$$

Multiplying the first equation by $\cos(\varphi-\alpha)$ and the second equation by $\sin(\varphi-\alpha)$, and adding, leads to:

$$C[\cos\psi\cos(\varphi-\alpha) + \sin\psi\sin(\varphi-\alpha)] - D_1 = 0$$

or

$$D_1 = C\cos(\varphi-\alpha-\psi) \quad (30)$$

Similarly, multiplying the first equation by $\sin(\varphi-\alpha)$ and the second by $\cos(\varphi-\alpha)$ and adding, yields:

$$C[\sin(\varphi-\alpha)\cos\psi-\cos(\varphi-\alpha)\sin\psi] + r-C_1 = 0$$

or

$$C_1 = r + C\sin(\varphi-\alpha-\psi) \quad (31)$$

Figure 6 depicts the pallet pin in entrance engagement with the escape wheel. The contact force P on the pin, and the associated friction force μP, (μ represents the coefficient of friction) act in the directions shown, which are opposite to the directions of the forces applied on the escape wheel tooth.

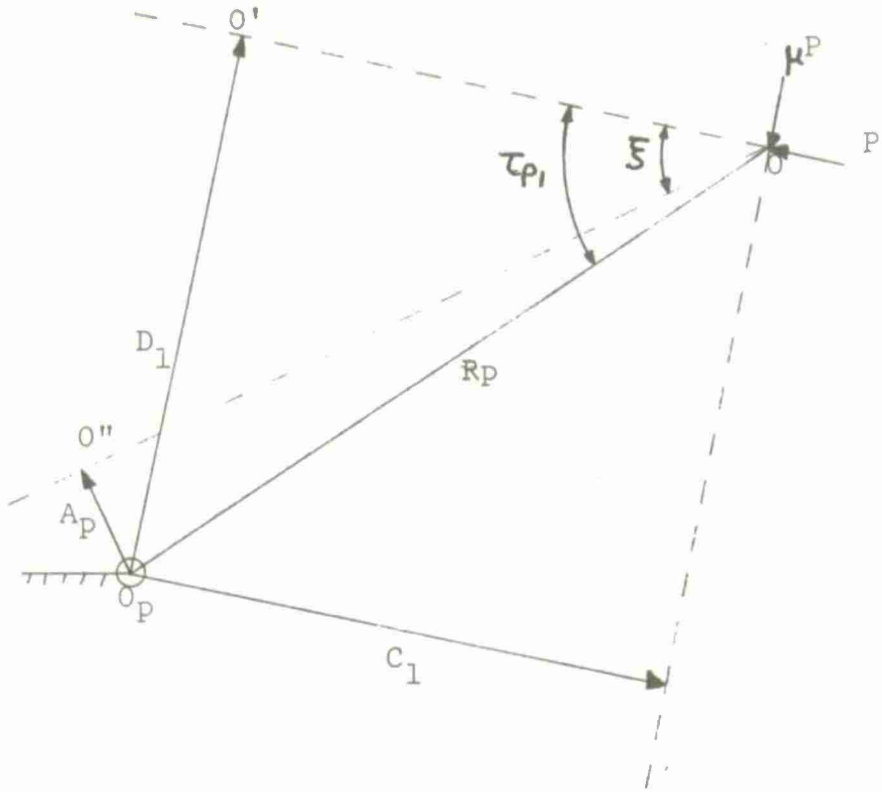

Figure 6. Pallet - entrance engagement.

As before, the introduction of the friction force causes the line of action of the contact force, 00', to be displaced an angle ξ to line 00", where

$$\xi = \tan^{-1}\mu$$

Letting

$$\measuredangle 0'00_p = \tau p_1$$

where

$$\tau p_1 = \tan^{-1} \frac{D_1}{C_1} \tag{32}$$

and

$$\measuredangle 0'00'' = \xi$$

then:

$$\measuredangle 0''00_p = \tau p_i - \xi$$

$$\text{With } R_p = \sqrt{C_1{}^2 + D_1{}^2} \tag{33}$$

the moment arm for the resultant force is given by:

$$A_p = R_p \sin(\tau p - \xi) \tag{34}$$

Angular Velocity Ratio

The instantaneous angular velocity ratio, which is obtained by taking the ratio of the (uncorrected) moment arms of the contact force about the escape wheel and pallet pivots, becomes:

$$N = \frac{A_1}{D_1} \tag{35}$$

Torque Transfer Ratio

The ratio of the friction corrected moment arms is defined as the instantaneous torque transfer ratio, which is given by:

$$N_f = \frac{A_w}{A_p} \tag{36}$$

Note that in the absence of friction, this expression is identical to equation (35).

Torque Transmission Efficiency

Finally, the efficiency E of torque transmission may be defined as the ratio of the torque transmitted to the pallet when friction is present to the torque transmitted in the absence of friction, i.e.,

$$E = \frac{A_p}{A_w} \Big/ \frac{D_1}{A_1} = \frac{N}{N_f} \tag{37}$$

Upon making the appropriate substitutions, the above equation may be written as:

$$E = \frac{1-\mu\left(\frac{C_1}{D_1}\right)}{1+\mu\left(\frac{B_1}{A_1}\right)} \tag{38}$$

The quantity is a measure of the amount of the available torque actually transmitted to the pallet.

A similar analysis to the one described above is performed for positions in exit engagement. In this phase, the direction of rotation of the pallet is opposite to that of the escape wheel.

Figure 7 shows the forces acting on the escape wheel in exit engagement. Proceeding in a manner similar to that used in the analysis of entrance engagement, the following relationships are obtained:

$$Rw = \sqrt{B_1{}^2+A_1{}^2} \tag{39}$$

$$\tau w = \tan^{-1} \frac{A_1}{B_1} \tag{40}$$

$$\measuredangle 0'00'' = \xi$$

$$\measuredangle 0_s 00' = \tau w$$

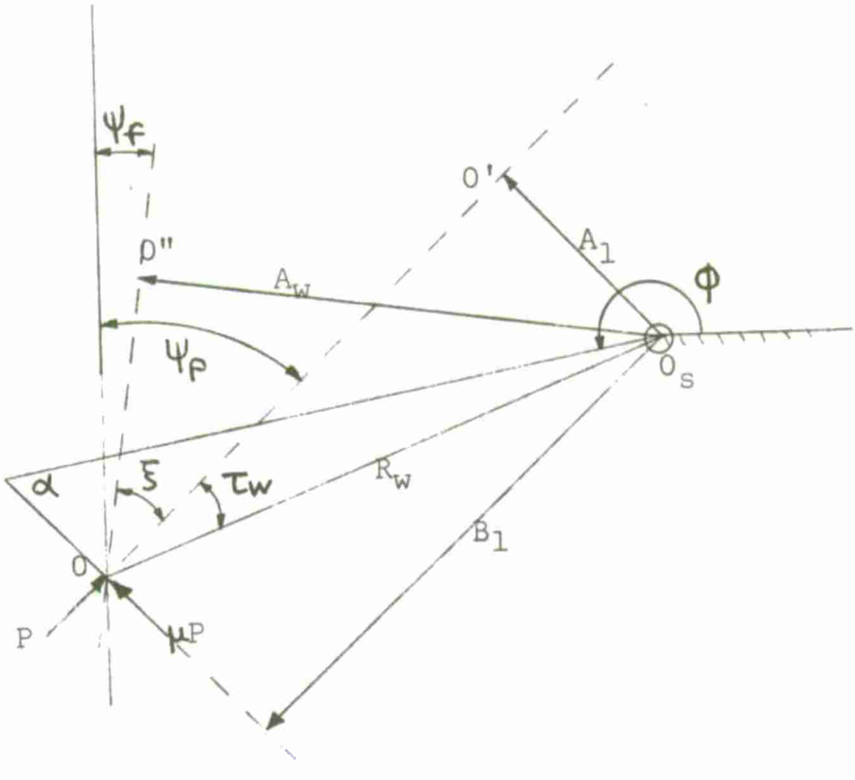

Figure 7. Escape wheel - exit engagement.

therefore;

$$\measuredangle 0_s 00'' = \tau w + \xi \tag{41}$$

and

$$Aw = Rw\sin(\tau w + \xi)$$

The pressure angle is given by:

$$\psi_p = \pi + \alpha - \varphi \tag{42}$$

and the friction corrected pressure angle becomes

$$\psi_f = \psi_p - \xi \tag{43}$$

In analyzing the pallet in exit engagement, it was discovered that two different modes of contact between the pallet pin and the escape wheel tooth exist. The first, which is illustrated in figure 8, occurs when the line of action of the friction force lies below the pallet pivot. In the second mode, illustrated in figure 9, the line of action of the friction force lies above the pallet pivot. Whether contact will be of the first or second mode depends solely on the geometry of the mechanism and on the operating center distance.

Mode one contact will be analyzed first. Following the same procedure employed in the analysis of the pallet in the entrance phase, the friction corrected moment arm and angle τ_{p2} become (fig. 8):

$$Rp = \sqrt{C_1{}^2 + D_1{}^2} \tag{44}$$

$$\tau_{p2} = 180° - \tan^{-1}\left(\frac{D_1}{C_1}\right) \tag{45}$$

The contact force P exerted on the pin, acts along the line of action 0L. When the friction force μP is introduced, the line of action 0L is rotated through ξ to a new position 00". Thus:

$$\measuredangle 0''0pL = \xi = \tan^{-1}\mu$$

$$\measuredangle L0p0 = \tau_{p2} - 90°$$

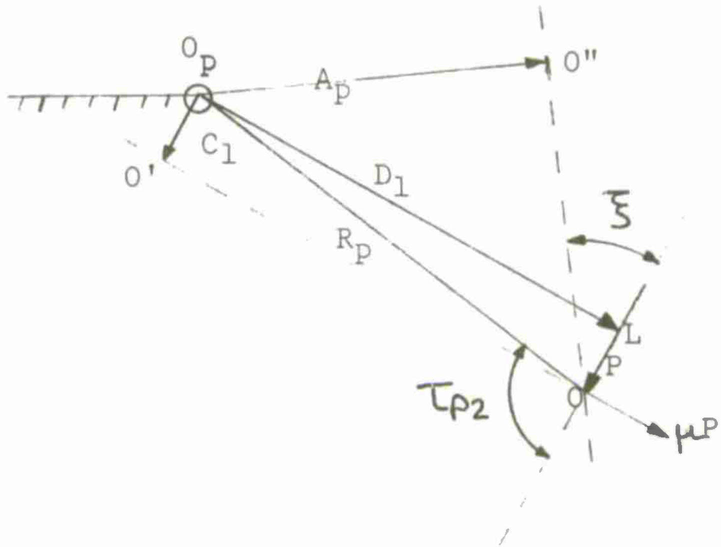

Figure 8. Pallet - exit engagement (mode 1)

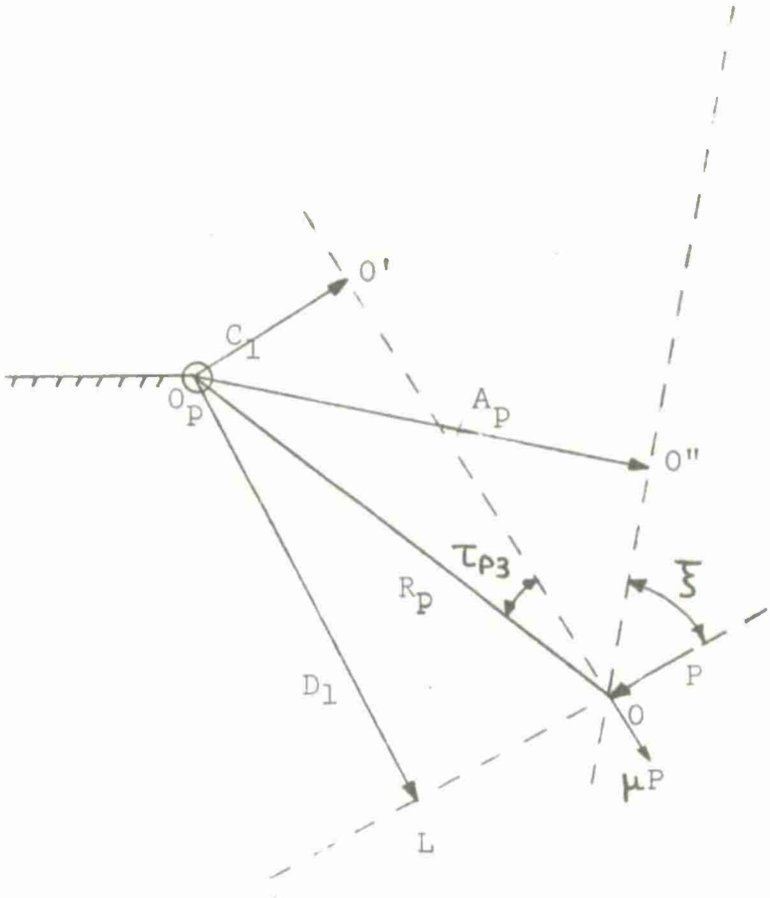

Figure 9. Pallet - exit engagement (mode 2)

therefore, $\measuredangle 0''0_p0 = \tau_{p2}-90°+\xi$

and $A_p = R_p\cos(\tau_{p2}-90°+\xi)$

or, $A_p = R_p\sin(\tau_{p2}+\xi)$ (46)

With equations (35) - (37) an expression for the efficiency of torque transmission for exit engagement with mode 1 contact may be obtained:

$$E = \frac{1-\mu\left(\frac{C_1}{D_1}\right)}{1+\mu\left(\frac{B_1}{A_1}\right)} \tag{47}$$

Note that this equation is identical to equation (38).

For mode 2 contact the following relationships occur (fig. 9):

$$R_p = \sqrt{C_1{}^2+D_1{}^2} \tag{48a}$$

$$\measuredangle 0_p00' = \tau_{p3} = \tan^{-1}\frac{C_1}{D_1} \tag{48b}$$

$$\measuredangle 0'00'' = 90°-\xi \tag{48c}$$

therefore: $\measuredangle 0_p00'' = \tau_{p3}+90°-\xi$ (49)

and $A_p = R_p\sin(\tau_{p3}+90°-\xi)$

or $A_p = R_p\cos(\tau_{p3}-\xi)$ (50)

Finally, with equations (35) - (37) the efficiency for mode 2 contact becomes:

$$E = \frac{1+\mu\left(\frac{C_1}{D_1}\right)}{1+\mu\left(\frac{B_1}{A_1}\right)} \tag{51}$$

DESCRIPTION OF COMPUTER PROGRAM

A listing of the FORTRAN computer program developed to perform this analysis is presented in appendix A. The program places the escapement in the starting position for the entrance half cycle (i.e., φ corresponds to a g=gmax, refer to eq. (18)) and all kinematic properties are computed for this position. The position of the escape wheel is then indexed by an amount DELPHI (.01 radians), and the kinematic properties are recomputed for this new position. This process is repeated until the entrance half cycle is completed (i.e., corresponds to g=0, refer to eq. (22)). The escapement is then placed in the starting position for the exit phase, and the above operation is repeated for the entire range of exit positions.

The program consists of four basic sections. In the first, the input data is read in. Below is a listing of the input parameters and their definitions. These are read in on a single card, with a format of 6F10.5. All of the input information is available from the engineering drawings of the escapement components.

Parameter	Explanation
A	Distance between pivots of escape wheel and pallet
B	Escape wheel radius
C	Pallet radius to center of pallet pin (equal on top and on bottom)
R	Pallet pin radius (equal on top and bottom)
ALPHA	Escape wheel tooth half angle
DELTA	Angle between escape wheel teeth

The program will perform calculations for four different values of the coefficient of friction (MU(1), MU(2), MU(3), MU(4)). These are read in on the second, and last, data card, in a format of 4F10.3. This will enable the user to determine the sensitivity of the escapement to friction.

The next section determines the quantities gmax (GMAX), the starting positions $\varphi_{M1,2}$ for the entrance half cycle (PHIIEN), and exit half cycle (PHIIEX) and the end position $\varphi_{01,2}$ of the entrance half cycle (PHIFEN) and exit half cycle (PHIFEX).

The last two sections compute the values of the kinematic parameters for the entrance and exit half cycles. At the beginning of each section, the program calls subroutine CALCUL. This subroutine determines the value of g and the pallet angle ψ for the position which will be analyzed next. With this information the program is then able to compute the instantaneous velocity ratio (QN), the rate of change of the instantaneous velocity ratio with respect to escape wheel angle (QNPRIM), and the friction corrected moment arms (AW,AP), the friction corrected angle (PSIF) and the efficiency (EFF) for each value of the coefficient of friction at each position of the entrance and exit half cycles. These quantities are printed out in tabular form, as shown in the sample output of appendix B.

SAMPLE CASE-M125A1 BOOSTER PIN PALLET ESCAPEMENT

The pin pallet escapement of the M125A1 Booster was analyzed as a sample application of this program. A drawing of this escapement is presented in figure 10. Nominal dimensions for the escapement geometry were used for input, and these are listed below, along with the four values of the coefficient of friction to be used in this study. The program output is given in appendix B, and is discussed below.

Input parameter	Dimension
A	.5182 cm (.204 in.)
B	.4877 cm (.192 in.)
C	.1991 cm (.0784 in.)
R	.0362 cm (.01425 in.)
ALPHA	51.0000°
DELTA	30.0000°
MU(I)	.1, .2, .3, .4

The position of the escape wheel when coupled motion first begins (corresponding to g=gmax) is given by $\varphi_{M1,2}$. For this escapement, these values were found to be

$$\varphi_{M1} = 142.580°$$

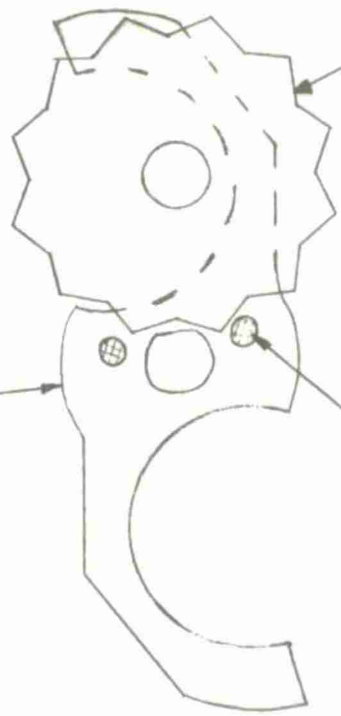

Figure 10. M125A1 booster pin pallet escapement.

for the entrance cycle, and

$$\varphi_{M2} = 187.420°$$

for the exit cycle.

The escape wheel angles $\varphi_{o1,2}$ corresponding to the position when the pallet pin leaves the escape wheel tooth (i.e., g=0), were computed to be

$$\varphi_{o1} = 155.185°$$

for entrance engagement, and

$$\varphi_{o2} = 199.452°$$

for exit engagement.

Thus, during the entrance half cycle, the escape wheel rotates 12.6° and during the exit half cycle it rotates 12.0°.

Velocity Ratio

Figures 11 and 12 depict the instantaneous angular velocity ratio between the pallet and the escape wheel as a function of the escape wheel position. Note that as this ratio increases the angular velocity of the pallet with respect to the escape wheel decreases. For entrance engagement, this ratio ranged from 1.084 at the beginning of the half cycle to 1.709 at the end. Thus, in entrance, the pallet angular velocity decreases as the pin approaches the escape wheel tip. For exit, this ratio was determined to be .970 at the starting position of the half cycle, and 2.213 at the end of the half cycle. It can be seen that the pallet will have its highest angular velocity with respect to the escape wheel at the beginning of the exit half cycle, but will be slowest at the end of the exit half cycle.

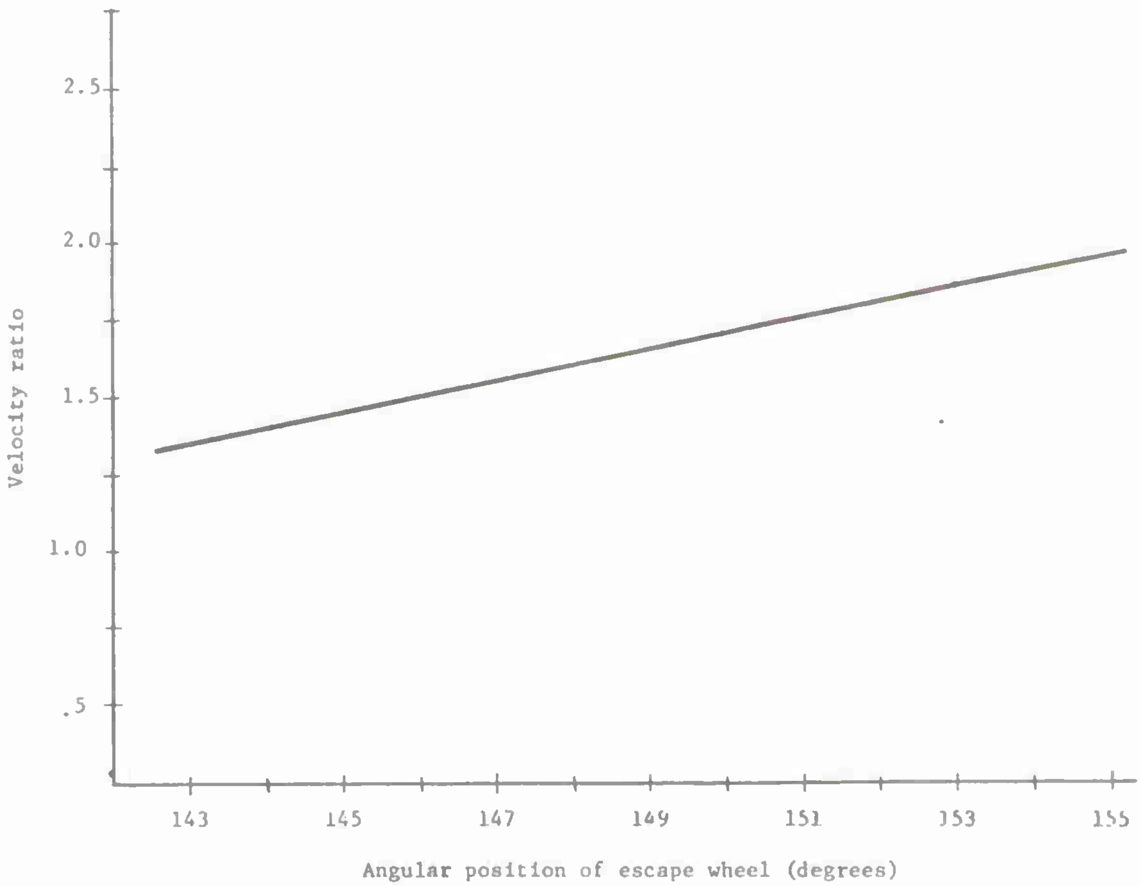

Figure 11. Velocity ratio - entrance engagement.

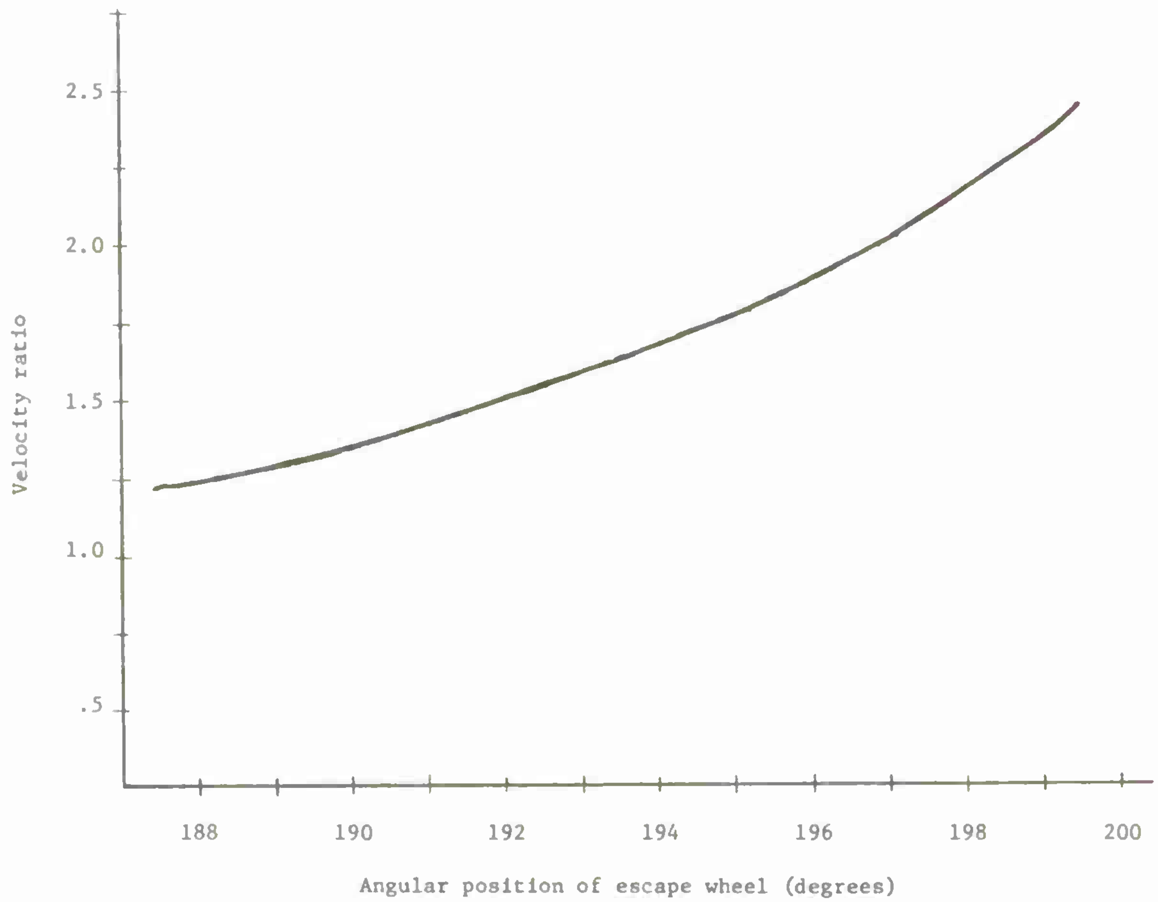

Figure 12. Velocity ratio - exit engagement

Efficiency

The computations showed that the minimum values of the torque transmission efficiency occur at the beginning of the entrance half cycle (see fig. 13). These values were determined to be 76.2%, 59.4%, 46.8%, and 37.0%, for coefficients of friction of .1, .2, .3, and .4 respectively. The peak efficiency for entrance engagement occurred at the end of the half cycle, where the pallet pin contacted the tip of the escape wheel tooth. Values here were computed to be 82.8%, 69.1%, 57.8%, and 48.4% for the above coefficients of friction.

Efficiencies in exit (fig. 14) were found to be higher than those in entrance. At the beginning of this half cycle values attained were 82.0%, 69.3%, 59.8%, and 52.4%. The maximum values of the torque transmission efficiency, which occurred at the intermediate position of the exit half cycle, were 83.1%, 70.3%, 60.5%, and 52.8%, for the four friction coefficients. At the final pallet pin position, the efficiencies decreased to values of 81.9%, 67.5%, 55.6%, and 45.8%.

Moment Arms

Figures 15 and 16 show the variation of the output and input force moment arms, as a function of the angular position of the escape wheel, for entrance engagement. In the absence of friction, values of the output force moment arm (A1) ranged from .185 cm (.073 in.) to .304 cm (.120 in.). Minimum friction corrected output force moment arms (AW) had values of .221 cm (.087 in.), .257 cm (.101 in.), .287 cm (.113 in.), and .312 cm (.123 in.) for coefficients of friction of .1, .2, .3, and .4 respectively. Maximum values were .343 cm (.135 in.), .373 cm (.147 in.), .401 cm (.158 in.), and .424 cm (.167 in.). Variations in the input force moment arms were not as great as those in the output force moment arms. Values for the uncorrected (no friction) input force moment arms (D1) ranged from .170 cm (.067 in.) to .178 cm (.070 in.). Minimum values of the friction corrected input force moment arms were .155 cm (.061 in.), .140 cm (.055 in.), .124 cm (.049 in.), and .107 cm (.042 in.). Maximum values were .165 cm (.065 in.), .152 cm (.060 in.), .137 cm (.054 in.), and .119 cm (.047 in.). In all cases, the minimum values occurred at the start of the entrance half cycle, and the maximum values occurred at the end of the entrance half cycle.

In a similar manner, figure 17 shows the variation of the input force moment arms, as a function of the angular position of the escape wheel, for exit engagement. Upon inspection of the computer output, it will be seen that the values of the output force moment arms for exit engagement are identical to those for entrance engagement.

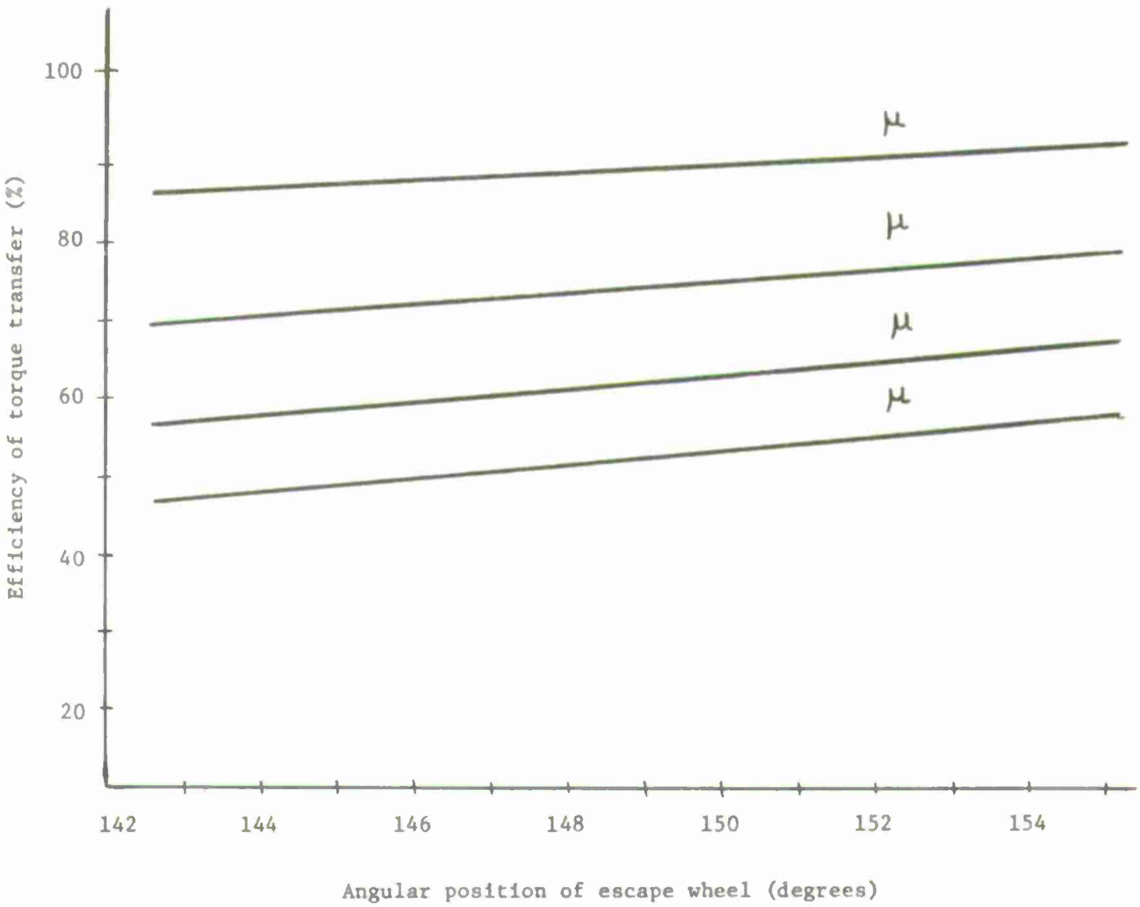

Figure 13. Efficiency - entrance engagement.

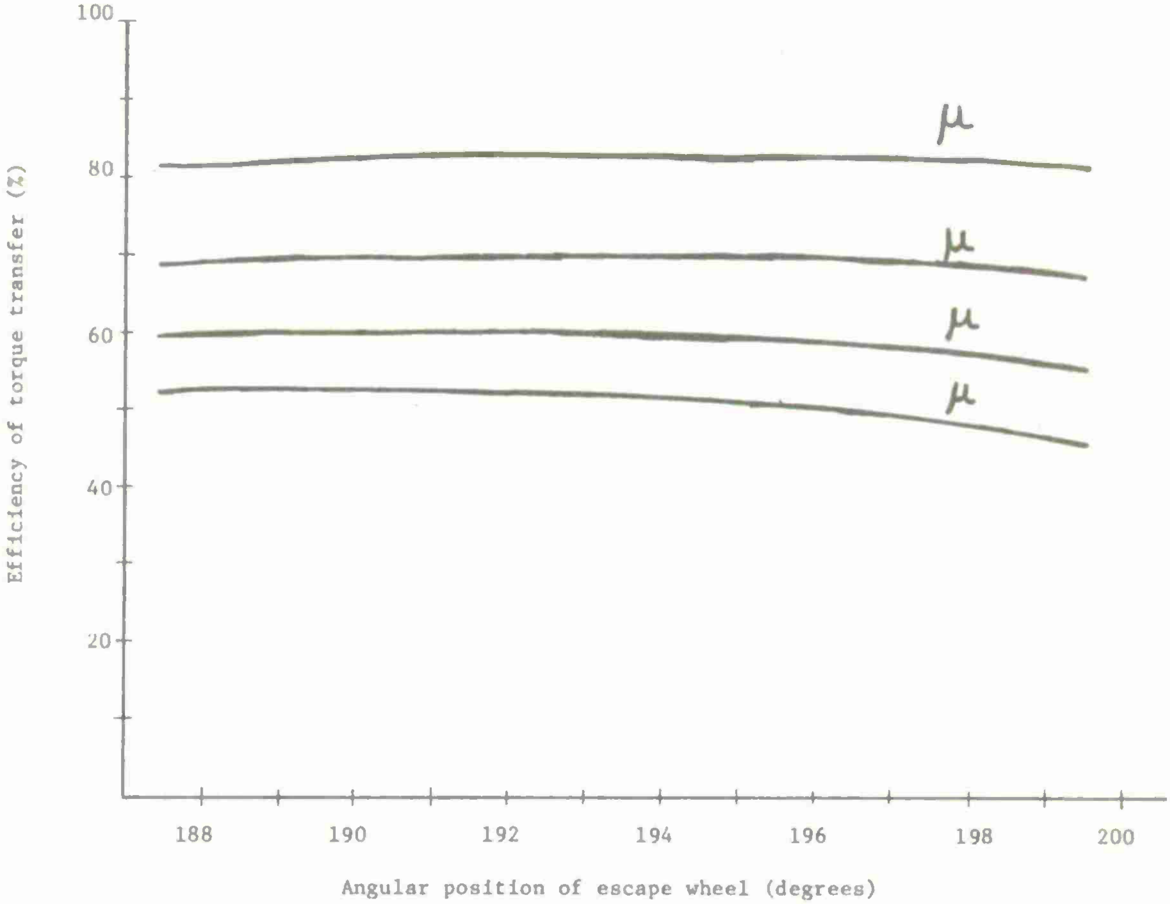

Figure 14. Efficiency - exit engagement.

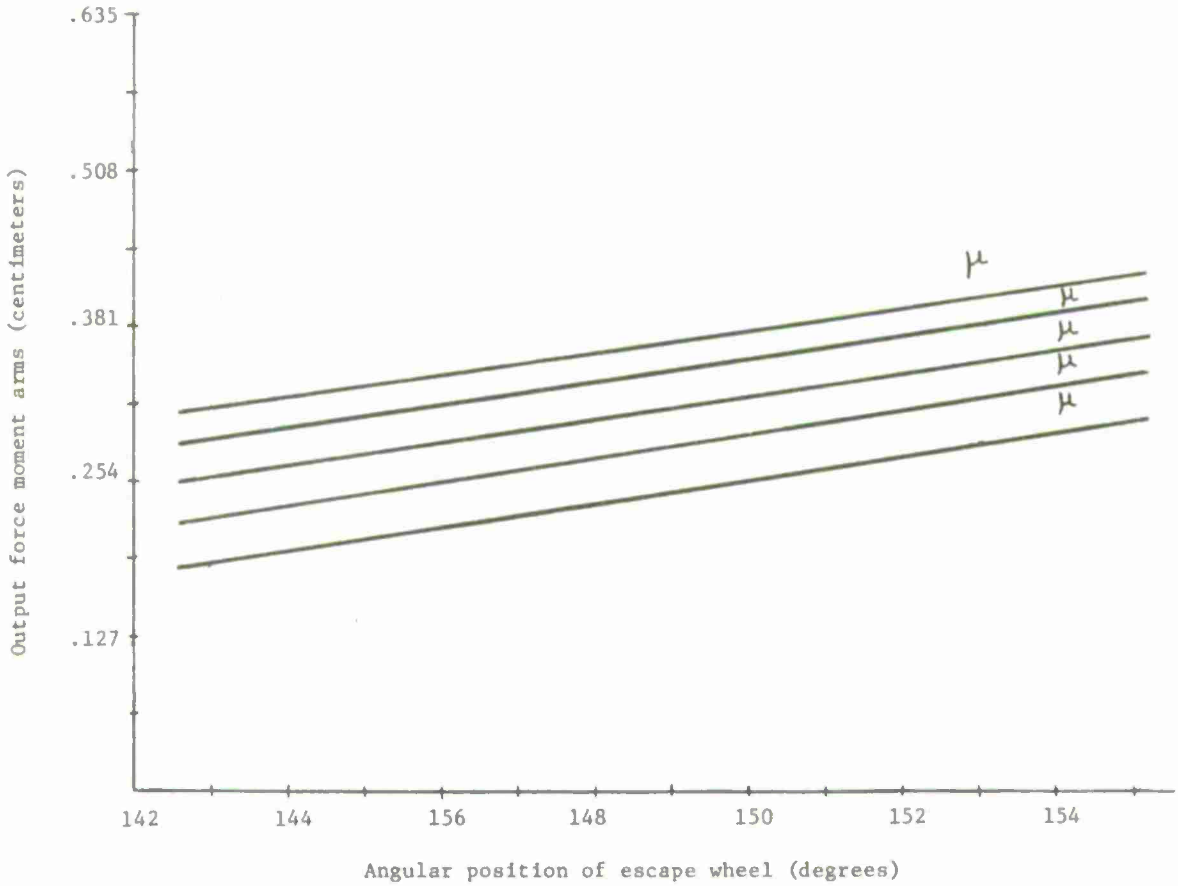

Figure 15. Output force moment arms - entrance engagement.

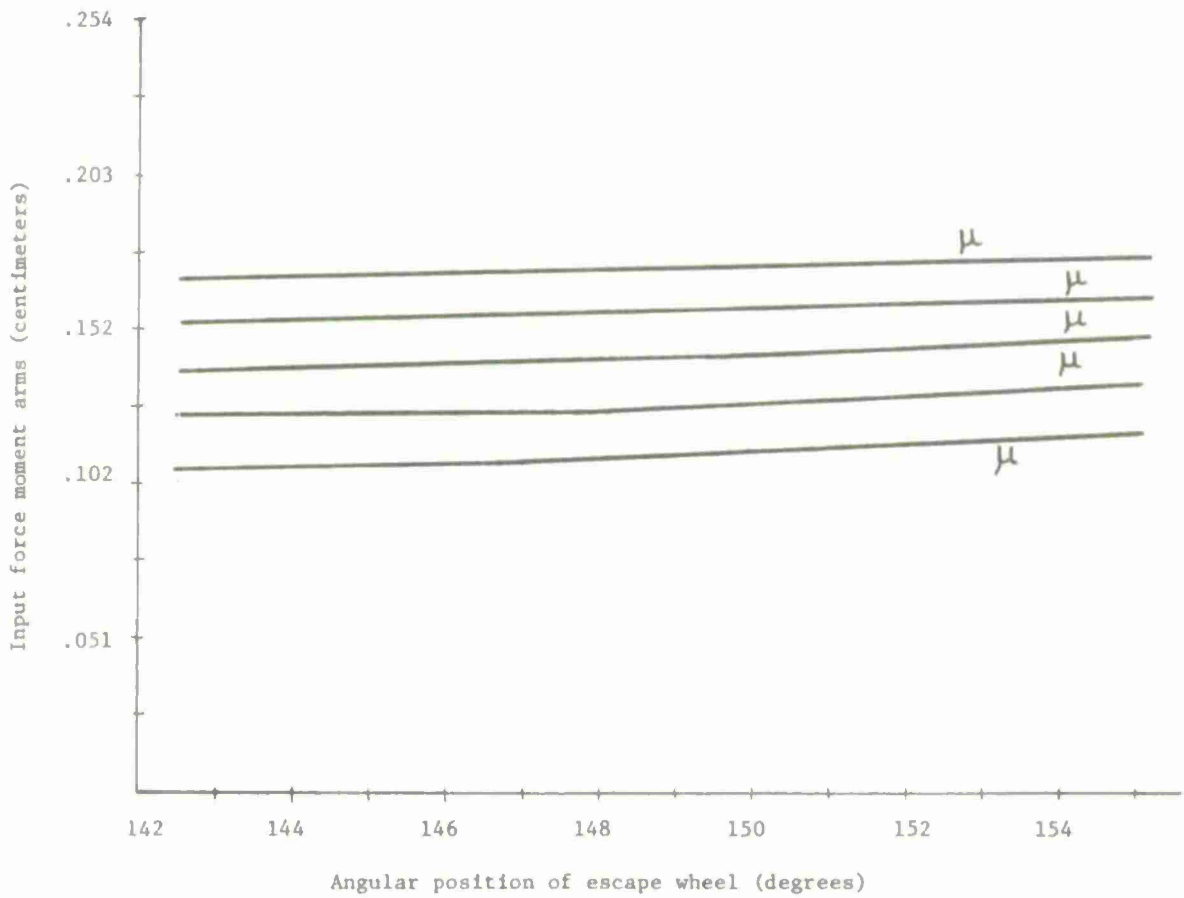

Figure 16. Input force moment arms - entrance engagement.

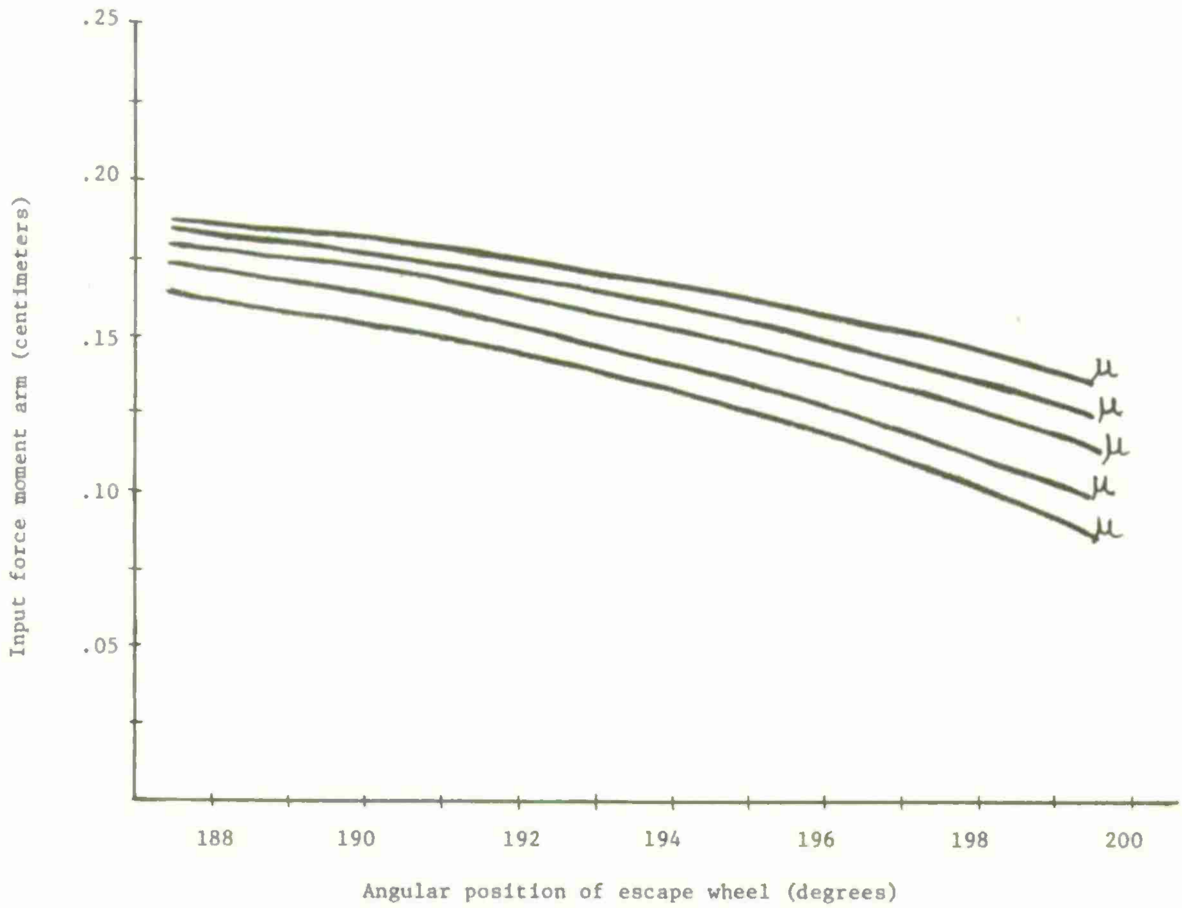

Figure 17. Input force moment arm - exit engagement.

The magnitude of the uncorrected input force moment arm ranged from .191 cm (.075 in.) to .137 cm (.054 in.). Maximum values of the friction corrected input force moment arms were .188 cm (.074 in.), .183 cm (.072 in.), .175 cm (.069 in.), and .168 cm (.066 in.). Minimum values were .127 cm (.050 in.), .114 cm (.045 in.), .102 cm (.040 in.), and .086 cm (.034 in.). For exit engagement, the minimum values occurred at the end of the half cycle, and the maximum values occurred at the start of the half cycle.

EFFECT OF VARIATION IN CENTER DISTANCE

Due to the possibility of two different modes of contact in the exit phase, a study was undertaken to determine the effects of variations in the pivot center distance on the other system parameters. This was accomplished by exercising the computer program using a center distance of A = .582 cm (.229 in.) representing an increase in the nominal value of 12%, and for A = .503 cm (.198 in.) corresponding to a decrease of 3%. Larger percent decreases in the center distance could not be investigated, as interference between the pallet pins and the escape wheel teeth would occur. All other input parameters remained at their nominal values. The computer output for the first case is presented in appendix C and for the latter case in appendix D. Table 1 summarizes the results of this study.

Increased Center Distance

Increasing the center distance resulted in a decrease in angular displacement of the entrance half cycle while increasing the displacement of the exit half cycle. Table 1 shows that entrance engagement for an extended center distance begins at a later position than it does for the nominal configuration, while exit engagement begins at an earlier position. The escape wheel rotates only 9.74° during the entrance half cycle (compared to 12.6° for the nominal center distance), while it rotates 14.9° during the exit half cycle (compared to 12.0°).

The instantaneous angular velocity ratios for the escapement with increased center distance were higher than those of the nominal configuration in the entrance half cycle, but lower than those of the nominal configuration in the exit half cycle. For entrance engagement, the ratio ranged from 1.602, at the beginning of the half cycle, to 2.192 at the end. In exit, the range was .934 to 1.718. This indicates that the pallet would have a lower angular velocity in entrance and a higher angular velocity in exit than in the nominal configuration. Furthermore, although the pallet would still have its highest

Table 1. Effects of variations in center distance*

		Nominal C.D. 0.518(0.204)		Increased C.D. 0.582(0.229)		Decreased C.D. 0.503(0.198)	
		Entrance engagement					
Angle start of coupled motion (φ_{M1})		142.580°		147.860°		141.690°	
Angle at end of coupled motion (φ_{01})		155.185°		157.600°		154.870°	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Velocity ratio		1.084	1.709	1.602	2.192	1.034	1.651
Efficiency	μ=.1	.762	.828	.687	.776	.772	.837
	μ=.2	.594	.691	.465	.596	.611	.707
	μ=.3	.468	.578	.300	.449	.490	.600
	μ=.4	.370	.484	.171	.326	.397	.511
Output force moment arms	μ=0.0	.185(.073)	.305(.120)	.185(.073)	.305(.120)	.185(.073)	.305(.120)
	μ=.1	.221(.087)	.343(.135)	.221(.087)	.343(.135)	.221(.087)	.343(.135)
	μ=.2	.257(.101)	.373(.147)	.257(.101)	.373(.147)	.257(.101)	.373(.147)
	μ=.3	.287(.113)	.401(.158)	.287(.113)	.401(.158)	.287(.113)	.401(.158)
	μ=.4	.312(.123)	.424(.167)	.312(.123)	.424(.167)	.312(.123)	.424(.167)
Input force moment arms	μ=0.0	.170(.067)	.178(.070)	.114(.045)	.140(.055)	.178(.070)	.185(.073)
	μ=.1	.155(.061)	.165(.065)	.094(.037)	.122(.048)	.165(.065)	.173(.068)
	μ=.2	.140(.055)	.152(.060)	.074(.029)	.102(.040)	.150(.059)	.160(.063)
	μ=.3	.124(.049)	.137(.054)	.053(.021)	.081(.032)	.135(.053)	.145(.057)
	μ=.4	.107(.042)	.119(.047)	.033(.013)	.064(.025)	.119(.047)	.132(.052)

*All dimensions are in centimeters; dimensions in parentheses are in inches.

Table 1. (Continued)

		Nominal C.D. 0.518(0.204)		Increased C.D. 0.582(0.229)		Decreased C.D. 0.503(0.198)	
		Exit engagement					
Mode of contact		Mode 1		Mode 2-Mode 1		Mode 1	
Angle at start of coupled motion (φ_{M2})		187.420°		182.140°		188.310°	
Angle at end of coupled motion (φ_{o2})		199.452°		197.040°		199.770°	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Velocity ratio		0.970	2.213	0.934	1.718	1.000	2.420
Efficiency	μ=.1	.820	.831	.855	.867	.806	.822
	μ=.2	.693	.703	.752	.764	.650	.688
	μ=.3	.598	.605	.662	.684	.523	.586
	μ=.4	.524	.528	.587	.621	.416	.506
Output force moment arms	μ=0.0	.185(.073)	.305(.120)	.185(.073)	.305(.120)	.185(.073)	.305(.120)
	μ=.1	.221(.087)	.343(.135)	.221(.087)	.340(.134)	.221(.087)	.340(.134)
	μ=.2	.257(.101)	.373(.147)	.257(.101)	.373(.147)	.257(.101)	.373(.147)
	μ=.3	.287(.113)	.401(.158)	.287(.113)	.401(.158)	.287(.113)	.401(.158)
	μ=.4	.312(.123)	.424(.167)	.312(.123)	.424(.167)	.312(.123)	.424(.167)
Input force moment arms	μ=0.0	.137(.054)	.191(.075)	.178(.070)	.198(.078)	.124(.049)	.185(.073)
	μ=.1	.127(.050)	.188(.074)	.170(.067)	.203(.080)	.114(.045)	.180(.071)
	μ=.2	.114(.045)	.183(.072)	.163(.064)	.206(.081)	.099(.039)	.173(.068)
	μ=.3	.102(.040)	.175(.069)	.155(.061)	.206(.081)	.086(.034)	.165(.065)
	μ=.4	.086(.034)	.168(.066)	.145(.057)	.206(.081)	.074(.029)	.157(.062)

angular velocity at the beginning of the exit half cycle, its lowest angular velocity would now occur at the end of the entrance half cycle.

Efficiencies in the entrance half cycle were much lower than those for the nominal configuration. Although the peak efficiency for entrance still occurred at the end of the half cycle, values were only 77.6%, 59.6%, 44.9%, and 32.6%. Minimum values, which occur at the beginning of the half cycle, were 68.7%, 46.5%, 30.0%, and 17.1%. It may be concluded that based on these reduced values of the efficiency, increasing center distances may result in undesirable torque transmission efficiencies.

The overall efficiencies in exit engagement were much higher than those for the nominal configuration. At the beginning of the half cycle values were 85.5%, 75.2%, 67.5%, and 61.5%. Peak values were 86.7%, 76.4%, 68.4%, and 62.1%, dropping off to 86.2%, 75.2%, 66.2%, and 58.7% at the end of the half cycle. While the effect of the increased center distance was to yield very high values of efficiency in the exit half cycle, this benefit was offset by the extremely low efficiencies encountered during entrance engagement.

Table 1 illustrates that the magnitudes of the output force moment arms did not vary from nominal values for both entrance and exit engagement, for the increased center distance. However, for entrance engagement, the magnitudes of the input force moment arms were much smaller than those of the nominal configuration but larger than those of the nominal configuration for exit engagement.

Finally, referring to the computer output of appendix C, it may be seen that mode 2 contact will occur for approximately one half of the exit phase. This is indicated by the negative values of C_1 (fig. 9).

Decreased Center Distance

The program was exercised using the minimum value of the center distance that does not cause interference .503 cm (.198 in.).

Whereas increasing the center distance decreased the length of entrance engagement, and increased the length of exit engagement, decreasing the center distance had the opposite effect (table 1). The escape wheel would now rotate 13.18° during the entrance half cycle, compared to the 12.6° rotation of the nominal configuration, and would rotate 11.46° during exit, as compared to 12.0° for the nominal configuration.

The effects of decreasing the center distance on the instantaneous angular velocity ratio were also opposite to those produced by an increased center distance. For entrance positions, the velocity ratios were lower than those of the nominal configuration, ranging from 1.034 at the start of the half cycle, to 1.651 at the end of the half cycle. Exit angular velocity ratios were higher than those of the nominal configuration, ranging from 1.000 to 2.420. Similar to the nominal configuration, the velocity of the pallet would be lower in exit, than in entrance, its highest velocity would be reached at the beginning of the exit phase, and the pallet would have its lowest velocity at the end of the exit phase.

Efficiencies in entrance were higher than those for the nominal configuration. Peak efficiencies still occurred at the end of the half cycle, with values of 83.7%, 70.7%, 60.0%, and 51.1%. Minimum values at the start of the entrance phase, were 77.2%, 61.1%, 49.0%, and 39.7%. Efficiencies in exit, however, were less than those for the nominal configuration. Peak values were 82.2%, 68.8%, 58.5%, and 50.6%. Minimum values, at the end of the exit phase were 80.6%, 65.0%, 52.3%, and 41.6%. These values do not represent a significant change in the ability of the escapement as a torque transfer mechanism.

Referring to table 1, it can be seen that, as in the case of increased center distance, the magnitudes of the output force moment arms did not vary from nominal values for both entrance and exit engagements. The magnitudes of the input force moment arms, however, were greater than those of the nominal configuration for entrance, and less than those of the nominal configuration for exit.

Lastly, the computer output of appendix D, shows that, as in the nominal configuration, only mode 1 contact will occur in the exit phase for the decreased center distance.

CONCLUSIONS

An analytic tool has been developed which can be used as a guide in the design of new pin pallet escapements or in the improvement of existing escapements. This can be accomplished by exercising the computer program to make parametic studies of proposed or existing designs instead of recourse to trial and error testing. For example, this work has been used to discover the significant influence the center distance has on the torque transmission efficiency of the pin pallet escapement.

RECOMMENDATIONS

It is recommended that the analytic tool which has been developed be applied when designing new or improving existing pin pallet runaway escapements. It is further recommended that this analysis be integrated with other studies to formulate a kinematic simulation of a complete S&A mechanism.

REFERENCE

1. G. G. Lowen and F. R. Tepper, "Dynamics of the Runaway Escapement," Fuze Development Branch Information Report No. 94, February 1977.

APPENDIX A

COMPUTER PROGRAM

PROGRAM PINPAL   74/74   OPT=1   FTN 4.6+420   01/11/78 11.42.29   PAGE   1

```
      PROGRAM PINPAL(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION AW(4),AP(4),PSIF(4),EFF(4,200),PHI(200),QNPRIM(200)
      REAL L,M,N,LO,MO,NO,MU(4),NQ(200)
C
C  READ IN AND WRITE DATA
C
      READ(5,1)A,B,C,R,ALPHA,DELTA
    1 FORMAT(6F10.5)
      WRITE(6,2)A,B,C,R,ALPHA,DELTA
    2 FORMAT(*1A =*,F7.5,3X,*B =*,F7.5,3X,*C =*,F7.5,3X,*R =*,
     1F7.5,3X,*ALPHA =*,F7.2,3X,*DELTA =*,F7.2//)
      READ(5,3)(MU(I),I=1,4)
    3 FORMAT(4F10.3)
      WRITE(6,4)(MU(I),I=1,4)
    4 FORMAT(* MU(1) =*,F5.3,3X,*MU(2) =*,F5.3,3X,*MU(3) =*,F5.3,
     13X,*MU(4) =*,F5.3)
      WRITE(6,5)
    5 FORMAT(*1   PHI*,5X,*AI*,5X,*DI*,17X,*AP*,27X,*AW*,15X,*PSIP*,
     117X,*PSIF*/*     DEG*,18X,2(*MU(1)  MU(2)  MU(3)  MU(4)    *),9X,
     2*MU(1)*,2X,*MU(2)*,2X,*MU(3)*,2X,*MU(4)*,10X,*C1*)
      PI = 3.14159
      Z = PI/180.
      ALPHAR = ALPHA*Z
      DELTAR = DELTA*Z
      BETAR = ALPHAR + DELTAR/2.
C
C  DETERMINATION OF GEOMETRIC PROPERTIES
C
      ST = R*SIN(DELTAR/2.)/SIN(PI-BETAR)
      GMAX = -(ST - R/TAN(BETAR))
      L = 2.*A*(GMAX*SIN(ALPHAR) - R*COS(ALPHAR))
      M = 2.*A*(GMAX*COS(ALPHAR) + B + R*SIN(ALPHAR))
      N = GMAX*GMAX + A*A + B*B + R*R - C*C + 2.*B*(GMAX*COS(ALPHAR)
     1+ R*SIN(ALPHAR))
      F1 =  -L + SQRT(L*L - N*N + M*M)
      F2 = N - M
      PHI1 = 2.*ATAN2(F1,F2)
      IF(PHI1 .LT. 0.)PHI1 = PHI1 + 2.*PI
      F11 = -L - SQRT(L*L - N*N + M*M)
      PHI2 = 2.*ATAN2(F11,F2)
      IF(PHI2 .LT. 0.)PHI2 = PHI2 + 2.*PI
      IF(PHI1 .LT. PHI2)PHI1EN = PHI1
      IF(PHI1 .LT. PHI2)PHI1EX = PHI2
      IF(PHI1 .LT. PHI2)GO TO 20
      PHI1EN = PHI2
      PHI1EX = PHI1
   20 LO = -2.*A*R*COS(ALPHAR)
      MO = 2.*A*(B + R*SIN(ALPHAR))
      NO = A*A + B*B + R*R - C*C + 2.*B*R*SIN(ALPHAR)
      F3 = -LO + SQRT(LO*LO - NO*NO + MO*MO)
      F33 = -LO - SQRT(LO*LO - NO*NO + MO*MO)
      F4 = NO - MO
      PHI3 = 2.*ATAN2(F3,F4)
```

```
      IF(PHI3 .LT. 0.)PHI3 = PHI3 + 2.*PI
      PHI4 = 2.*ATAN2(F33,F4)
      IF(PHI4 .LT. 0.)PHI4 = PHI4 + 2.*PI
      IF(PHI3 .LT. PHI4)PHIFEN = PHI3
      IF(PHI3 .LT. PHI4)GO TO 21
      PHIFEN = PHI4
      PHIFEX = PHI3
   21 J = 1
      PHI(J) = PHIIEN
      DELPHI = 0.01
      B1 = B*SIN(ALPHAR)
C
C  ENTRANCE
C
      QNP=0.0
    6 IF(PHI(J) .GT. PHIFEN)GO TO 90
      CALL CALCUL(A,B,C,R,ALPHAR,PHI(J),G,PSI)
      A1 = B*COS(ALPHAR) + G
      C1=-(R+C*SIN(PHI(J)+ALPHAR-PSI))
      D1 = C*COS(PHI(J) - ALPHAR - PSI)
      RW = SQRT(A1*A1 + B1*B1)
      RP = SQRT(C1*C1 + D1*D1)
      CC=ABS(C1)
      DD=ABS(D1)
      QN=A1/DD
      NQ(J)=A1/DD
      QNN=QN-QNP
      IF(J.EQ.1)QNPRIM(J)=0.
      IF(J.EQ.1)GO TO 25
      QNPRIM(J)=QNN/(PHI(J)-PHI(J-1))
      IF(QNP.EQ.0.0)QNPRIM(J)=0.0
   25 CONTINUE
      QNP=QN
      TAUP=ATAN2(DD,CC)
      TAUW = ATAN2(B1,A1)
      PSIP = PI - PHI(J) + ALPHAR
      DO 7 I = 1,4
      XSI = ATAN2(MU(I),1.)
      AP(I) = RP*SIN(TAUP - XSI)
      AW(I) = RW*COS(TAUW - XSI)
      PSIF(I) = PSIP - XSI
      EFF(I,J) = (1. - MU(I)*CC/DD)/(1. + MU(I)*B1/A1)
    7 CONTINUE
      PSIPD = PSIP/Z
      PSIF1D = PSIF(1)/Z
      PSIF2D = PSIF(2)/Z
      PSIF3D = PSIF(3)/Z
      PSIF4D = PSIF(4)/Z
      PHID = PHI(J)/Z
      WRITE(6,8)PHID,A1,D1,AP(1),AP(2),AP(3),AP(4),AW(1),AW(2),AW(3),
     1AW(4),PSIPD,PSIF1D,PSIF2D,PSIF3D,PSIF4D,C1
    8 FORMAT(F8.3,2X,F5.3,2X,F5.3,2X,2(F5.3,2X,F5.3,2X,F5.3,2X,F5.3,2X),
     1F6.2,1X,4(1X,F6.2),1X,*ENTRANCE*,1X,F5.3)
```

```
      J = J + 1
      PHI(J) = PHI(J-1) + DELPHI
      GO TO 6
C
C  EXIT
C
   90 ONP=0.0
    9 PHI(J) = PHIIEX
   10 IF(PHI(J) .GT. PHIFEX)GO TO 13
      CALL CALCUL(A,B,C,R,ALPHAR,PHI(J),G,PSI)
      AI = B*COS(ALPHAR) + G
      CI = -(R + C*SIN(PHI(J) - ALPHAR - PSI))
      DI =  C*COS(PHI(J) - ALPHAR - PSI)
      RW = SQRT(AI*AI + BI*BI)
      RP = SQRT(CI*CI + DI*DI)
      CC=ABS(CI)
      DD=ABS(DI)
      ON=AI/DD
      NO(J)=AI/DD
      ONN=ON-ONP
      ONPRIM(J)=ONN/(PHI(J)-PHI(J-1))
      IF(ONP.EQ.0.)ONPRIM(J)=0.0
      ONP=ON
      IF(CI.LT.0.0)GO TO 30
      TAUP = PI - ATAN2(DD,CC)
      TAUW = ATAN2(BI,AI)
      GO TO 18
   30 TAUP=ATAN2(CC,DD)
      TAUW=ATAN2(AI,BI)
   18 PSIP = PI - PHI(J) + ALPHAR
      DO 11 I = 1,4
      XSI = ATAN2(MU(I),1.)
      IF(CI.LT.0.0)GO TO 31
      AP(I) = RP*SIN(TAUP + XSI)
      AW(I) = RW*COS(TAUW - XSI)
      GO TO 23
   31 AW(I)=RW*SIN(TAUW+XSI)
      AP(I)=RP*COS(TAUP-XSI)
   23 PSIF(I) = PSIP - XSI
      IF(CI.LT.0.0)GO TO 32
      EFF(I,J) = (1. - MU(I)*CC/DD)/(1. + MU(I)*BI/AI)
      GO TO 11
   32 EFF(I,J)=(1.+MU(I)*CC/DD)/(1.+MU(I)*BI/AI)
   11 CONTINUE
      PSIPO = PSIP/Z
      PHID = PHI(J)/Z
      PSIF1D = PSIF(1)/Z
      PSIF2D = PSIF(2)/Z
      PSIF3D = PSIF(3)/Z
      PSIF4D = PSIF(4)/Z
      WRITE(6,12)PHID,AI,DI,AP(1),AP(2),AP(3),AP(4),AW(1),AW(2),AW(3),
     1AW(4),PSIPO,PSIF1D,PSIF2D,PSIF3D,PSIF4D,CI
   12 FORMAT(F8.3,2X,F5.3,2X,F5.3,2X,2(F5.3,2X,F5.3,2X,F5.3,2X,F5.3,2X),
```

```
         1F6.2,1X,4(1X,F6.2),1X,*EXIT*,5X,F5.3)
          J = J + I
          PHI(J) = PHI(J-1) + DELPHI
          GO TO 10
       13 WRITE(6,14)
       14 FORMAT(*1   PHI*,12X,*EFFICIENCY*,9X,*VELOCITY RATIO*,5X,*N PRIME*
         1/*    DEG*,1X,*MU(1)*,2X,*MU(2)*,2X,*MU(3)*,2X,*MU(4)*)
          JEND = J - I
          DO 16 J = 1,JEND
          PHID = PHI(J)/2
          WRITE(6,15)PHID,EFF(1,J),EFF(2,J),EFF(3,J),EFF(4,J),NQ(J),QNPRIM(J
         1)
       15 FORMAT(F8.3,4(2X,F5.3),5X,F8.3,8X,F8.3)
       16 CONTINUE
          STOP
          END
```

```
      SUBROUTINE CALCUL(A,B,C,R,ALPHAR,PHI,G,PSI)
      REAL K
      H = 2.*(B*COS(ALPHAR) - A*COS(PHI - ALPHAR))
      K = A**2 + B**2 + R**2 - C**2 + 2.*B*R*SIN(ALPHAR) + 2.*A*B
     1*COS(PHI) - 2.*A*R*SIN(PHI - ALPHAR)
      G1 = (-H + SQRT(H**2 - 4.*K))/2.
      G2 = (-H - SQRT(H**2 - 4.*K))/2.
      IF(ABS(G1) .LT. ABS(G2))GO TO 1
      G = G2
      GO TO 2
    1 G = G1
    2 P = B*SIN(PHI) + G*SIN(PHI - ALPHAR) + R*COS(PHI - ALPHAR)
      PSI = ASIN(P/C)
      IF(PSI .LT. 0.)GO TO 3
      GO TO 4
    3 PSI = 2.*3.14159 - ABS(PSI)
    4 RETURN
      END
```

APPENDIX B

COMPUTER OUTPUT FOR NOMINAL CONFIGURATION

A = .20400   B = .19200   C = .07840   R = .01425   ALPHA = 51.00   DELTA = 30.00

MU(1) = .100   MU(2) = .200   MU(3) = .300   MU(4) = .400

PWI DEG	AI	BI	AP MU(1)	AP MU(2)	AP MU(3)	AP MU(4)	AW MU(1)	AW MU(2)	AW MU(3)	AW MU(4)	PSIP	PSIF MU(1)	PSIF MU(2)	PSIF MU(3)	PSIF MU(4)		CI
142.580	.073	.067	.061	.055	.049	.042	.087	.101	.113	.123	88.42	82.71	77.11	71.72	66.62	ENTRANCE	-.055
143.153	.075	.067	.061	.055	.049	.042	.089	.103	.115	.125	87.85	82.14	76.54	71.15	66.05	ENTRANCE	-.055
143.726	.077	.067	.061	.055	.049	.042	.091	.105	.117	.127	87.27	81.56	75.96	70.57	65.47	ENTRANCE	-.055
144.299	.079	.067	.062	.055	.049	.042	.094	.107	.119	.129	86.70	80.99	75.39	70.00	64.90	ENTRANCE	-.054
144.872	.081	.067	.062	.055	.049	.042	.096	.109	.121	.131	86.13	80.42	74.82	69.43	64.33	ENTRANCE	-.054
145.445	.083	.067	.062	.056	.049	.043	.098	.111	.123	.133	85.56	79.84	74.25	68.86	63.75	ENTRANCE	-.054
146.018	.085	.068	.062	.056	.049	.043	.100	.113	.125	.135	84.98	79.27	73.67	68.28	63.18	ENTRANCE	-.054
146.591	.088	.068	.062	.056	.049	.043	.102	.115	.127	.137	84.41	78.70	73.10	67.71	62.61	ENTRANCE	-.054
147.164	.090	.068	.062	.056	.050	.043	.104	.117	.129	.139	83.84	78.13	72.53	67.14	62.03	ENTRANCE	-.054
147.737	.092	.068	.062	.056	.050	.043	.106	.119	.131	.141	83.26	77.55	71.95	66.56	61.46	ENTRANCE	-.053
148.309	.094	.068	.062	.056	.050	.043	.108	.121	.133	.143	82.69	76.98	71.38	65.99	60.89	ENTRANCE	-.053
148.882	.096	.068	.063	.057	.050	.044	.111	.124	.135	.145	82.12	76.41	70.81	65.42	60.32	ENTRANCE	-.053
149.455	.098	.068	.063	.057	.050	.044	.113	.126	.137	.147	81.54	75.83	70.23	64.85	59.74	ENTRANCE	-.053
150.028	.101	.069	.063	.057	.051	.044	.115	.128	.139	.149	80.97	75.26	69.66	64.27	59.17	ENTRANCE	-.052
150.601	.103	.069	.063	.057	.051	.045	.117	.130	.141	.151	80.40	74.69	69.09	63.70	58.60	ENTRANCE	-.052
151.174	.105	.069	.063	.057	.051	.045	.119	.132	.143	.153	79.83	74.12	68.52	63.13	58.02	ENTRANCE	-.052
151.747	.107	.069	.064	.058	.052	.045	.121	.134	.146	.155	79.25	73.54	67.94	62.55	57.45	ENTRANCE	-.051
152.320	.109	.069	.064	.058	.052	.046	.124	.137	.148	.157	78.68	72.97	67.37	61.98	56.88	ENTRANCE	-.051
152.893	.112	.070	.064	.058	.052	.046	.126	.139	.150	.159	78.11	72.40	66.80	61.41	56.31	ENTRANCE	-.050
153.466	.114	.070	.064	.059	.052	.046	.128	.141	.152	.161	77.53	71.82	66.22	60.83	55.73	ENTRANCE	-.050
154.039	.116	.070	.065	.059	.053	.047	.130	.143	.154	.163	76.96	71.25	65.65	60.26	55.16	ENTRANCE	-.050
154.612	.118	.070	.065	.059	.053	.047	.133	.145	.156	.165	76.39	70.68	65.08	59.69	54.59	ENTRANCE	-.049
155.185	.120	.070	.065	.060	.054	.047	.135	.147	.158	.167	75.82	70.10	64.51	59.12	54.01	ENTRANCE	-.049
187.420	.073	-.075	.074	.072	.069	.066	.087	.101	.113	.123	43.58	37.87	32.27	26.88	21.78	EXIT	.00
187.993	.075	-.075	.073	.071	.068	.065	.089	.102	.114	.125	43.01	37.30	31.70	26.31	21.21	EXIT	.010
188.566	.077	-.074	.073	.070	.068	.064	.091	.104	.116	.126	42.43	36.72	31.12	25.73	20.63	EXIT	.012
189.139	.078	-.073	.072	.069	.067	.063	.093	.106	.118	.128	41.86	36.15	30.55	25.16	20.06	EXIT	.013
189.712	.080	-.073	.071	.069	.066	.062	.095	.108	.120	.130	41.29	35.58	29.98	24.59	19.49	EXIT	.015
190.285	.082	-.072	.070	.068	.065	.061	.097	.110	.122	.132	40.72	35.00	29.41	24.02	18.91	EXIT	.016
190.858	.084	-.072	.069	.067	.063	.060	.099	.112	.124	.134	40.14	34.43	28.83	23.44	18.34	EXIT	.018
191.431	.086	-.071	.069	.066	.062	.059	.101	.114	.126	.136	39.57	33.86	28.26	22.87	17.77	EXIT	.019
192.004	.088	-.070	.068	.065	.061	.057	.103	.116	.128	.138	39.00	33.29	27.69	22.30	17.19	EXIT	.021
192.577	.091	-.069	.067	.064	.060	.056	.105	.118	.130	.139	38.42	32.71	27.11	21.72	16.62	EXIT	.022
193.150	.093	-.068	.066	.062	.059	.055	.107	.120	.132	.141	37.85	32.14	26.54	21.15	16.05	EXIT	.024
193.723	.095	-.067	.065	.061	.057	.053	.109	.122	.134	.143	37.28	31.57	25.97	20.58	15.48	EXIT	.026
194.296	.097	-.066	.063	.060	.056	.052	.111	.124	.136	.146	36.70	30.99	25.39	20.01	14.90	EXIT	.027
194.869	.099	-.065	.062	.058	.054	.050	.114	.127	.138	.148	36.13	30.42	24.82	19.43	14.33	EXIT	.029
195.442	.102	-.064	.061	.057	.053	.048	.116	.129	.140	.150	35.56	29.85	24.25	18.86	13.76	EXIT	.031
196.015	.104	-.063	.060	.056	.051	.047	.118	.131	.142	.152	34.99	29.27	23.68	18.29	13.18	EXIT	.032
196.587	.106	-.062	.058	.054	.049	.045	.121	.134	.145	.154	34.41	28.70	23.10	17.71	12.61	EXIT	.034
197.160	.109	-.061	.057	.052	.048	.043	.123	.136	.147	.157	33.84	28.13	22.53	17.14	12.04	EXIT	.036
197.733	.112	-.059	.055	.051	.046	.041	.126	.139	.150	.159	33.27	27.56	21.96	16.57	11.47	EXIT	.037
198.306	.114	-.058	.053	.049	.044	.039	.128	.141	.152	.161	32.69	26.98	21.38	15.99	10.89	EXIT	.039
198.879	.117	-.056	.052	.047	.042	.037	.131	.144	.155	.164	32.12	26.41	20.81	15.42	10.32	EXIT	.041
199.452	.120	-.054	.050	.045	.040	.034	.134	.147	.158	.167	31.55	25.84	20.24	14.85	9.75	EXIT	.042

PHI DEG	MU(1)	EFFICIENCY MU(2)	MU(3)	MU(4)	VELOCITY RATIO	N PRIME
142.580	.762	.594	.468	.370	1.084	0.000
143.153	.766	.599	.473	.375	1.114	3.029
143.726	.770	.604	.478	.380	1.144	3.022
144.299	.773	.608	.484	.385	1.174	3.013
144.872	.777	.613	.489	.390	1.204	3.002
145.445	.780	.618	.494	.395	1.234	2.989
146.018	.783	.623	.499	.400	1.264	2.974
146.591	.788	.627	.504	.406	1.294	2.958
147.164	.790	.632	.509	.411	1.323	2.940
147.737	.793	.636	.514	.416	1.352	2.921
148.309	.796	.641	.519	.421	1.381	2.900
148.882	.799	.645	.524	.426	1.410	2.878
149.455	.802	.649	.529	.431	1.439	2.854
150.028	.804	.654	.534	.436	1.467	2.830
150.601	.807	.658	.539	.441	1.495	2.804
151.174	.810	.662	.544	.447	1.523	2.778
151.747	.813	.666	.549	.452	1.550	2.751
152.320	.815	.671	.554	.457	1.577	2.723
152.893	.818	.675	.559	.463	1.604	2.694
153.466	.821	.679	.564	.468	1.631	2.665
154.039	.823	.683	.568	.473	1.657	2.636
154.612	.826	.687	.573	.479	1.683	2.606
155.185	.828	.691	.578	.484	1.709	2.576
187.420	.820	.693	.598	.524	.970	0.000
187.993	.822	.695	.600	.526	1.001	3.114
188.566	.824	.697	.601	.527	1.034	3.237
189.139	.825	.699	.603	.527	1.068	3.371
189.712	.827	.700	.604	.528	1.103	3.518
190.285	.828	.701	.604	.528	1.140	3.680
190.858	.829	.702	.605	.528	1.178	3.859
191.431	.830	.703	.605	.527	1.219	4.056
192.004	.830	.703	.605	.526	1.261	4.274
192.577	.831	.703	.604	.525	1.307	4.516
193.150	.831	.703	.603	.523	1.354	4.787
193.723	.831	.703	.602	.520	1.405	5.089
194.296	.831	.702	.600	.518	1.460	5.429
194.869	.831	.701	.598	.514	1.518	5.812
195.442	.831	.700	.595	.510	1.580	6.247
196.015	.830	.698	.592	.506	1.649	6.744
196.587	.829	.695	.588	.500	1.721	7.315
197.160	.828	.693	.584	.494	1.801	7.976
197.733	.826	.689	.578	.487	1.889	8.748
198.306	.824	.685	.572	.478	1.985	9.657
198.879	.822	.680	.565	.469	2.092	10.740
199.452	.819	.675	.556	.458	2.213	12.046

APPENDIX C

COMPUTER OUTPUT FOR NOMINAL CONFIGURATION WITH A = .582 CM (.229 IN.)

A = .22900   B = .19200   C = .07840   R = .01425   ALPHA = 51.00   DELTA = 30.00

MU(1) = .100   MU(2) = .200   MU(3) = .300   MU(4) = .400

PHI DEG	AI	DT	AP MU(1)	AP MU(2)	AP MU(3)	AP MU(4)	AW MU(1)	AW MU(2)	AW MU(3)	AW MU(4)	PSIP	PSIF MU(1)	PSIF MU(2)	PSIF MU(3)	PSIF MU(4)		CI
147.860	.073	.045	.037	.029	.021	.013	.087	.101	.113	.123	83.14	77.43	71.83	66.44	61.34	ENTRANCE	-.078
148.433	.075	.046	.038	.038	.022	.014	.090	.103	.115	.125	82.57	76.86	71.26	65.87	60.77	ENTRANCE	-.078
149.006	.078	.046	.038	.030	.022	.014	.093	.106	.118	.128	81.99	76.28	70.68	65.30	60.19	ENTRANCE	-.078
149.579	.081	.047	.039	.031	.023	.015	.095	.109	.120	.130	81.42	75.71	70.11	64.72	59.62	ENTRANCE	-.077
150.152	.084	.047	.039	.031	.023	.015	.098	.111	.123	.133	80.85	75.14	69.54	64.15	59.05	ENTRANCE	-.077
150.724	.086	.048	.040	.032	.024	.016	.101	.114	.126	.136	80.28	74.56	68.97	63.58	58.47	ENTRANCE	-.076
151.297	.089	.048	.040	.032	.024	.016	.104	.117	.128	.138	79.70	73.99	68.39	63.00	57.90	ENTRANCE	-.076
151.870	.092	.049	.041	.033	.025	.017	.106	.119	.131	.141	79.13	73.42	67.82	62.43	57.33	ENTRANCE	-.076
152.443	.095	.049	.042	.034	.026	.018	.109	.122	.134	.143	78.56	72.85	67.25	61.86	56.76	ENTRANCE	-.075
153.016	.098	.050	.042	.034	.026	.019	.112	.125	.136	.146	77.98	72.27	66.67	61.28	56.18	ENTRANCE	-.075
153.589	.100	.050	.043	.035	.027	.019	.115	.128	.139	.149	77.41	71.70	66.10	60.71	55.61	ENTRANCE	-.074
154.162	.103	.051	.043	.036	.028	.020	.118	.130	.142	.151	76.84	71.13	65.53	60.14	55.04	ENTRANCE	-.074
154.735	.106	.052	.044	.036	.028	.021	.120	.133	.144	.154	76.26	70.55	64.95	59.57	54.46	ENTRANCE	-.073
155.308	.109	.052	.045	.037	.029	.022	.123	.136	.147	.156	75.69	69.98	64.38	58.99	53.89	ENTRANCE	-.073
155.881	.112	.053	.045	.038	.030	.022	.126	.139	.150	.159	75.12	69.41	63.81	58.42	53.32	ENTRANCE	-.072
156.454	.115	.054	.046	.038	.031	.023	.129	.142	.153	.162	74.55	68.84	63.24	57.85	52.74	ENTRANCE	-.072
157.027	.117	.054	.047	.039	.032	.024	.132	.144	.155	.164	73.97	68.26	62.66	57.27	52.17	ENTRANCE	-.071
157.600	.120	.055	.048	.040	.032	.025	.135	.147	.158	.167	73.40	67.69	62.09	56.70	51.60	ENTRANCE	-.070
182.140	.073	-.078	.080	.081	.081	.081	.087	.101	.113	.123	48.86	43.15	37.55	32.16	27.06	EXIT	-.023
182.713	.074	-.078	.080	.081	.081	.081	.089	.102	.114	.124	48.29	42.58	36.98	31.59	26.49	EXIT	-.022
183.286	.076	-.078	.080	.081	.081	.080	.090	.104	.116	.126	47.71	42.00	36.40	31.01	25.91	EXIT	-.020
183.859	.077	-.078	.080	.080	.080	.080	.092	.105	.117	.127	47.14	41.43	35.83	30.44	25.34	EXIT	-.019
184.432	.079	-.078	.080	.080	.080	.079	.094	.107	.119	.129	46.57	40.86	35.26	29.87	24.77	EXIT	-.017
185.005	.081	-.078	.080	.080	.080	.079	.095	.108	.120	.130	45.99	40.28	34.68	29.30	24.19	EXIT	-.016
185.578	.082	-.078	.079	.080	.079	.078	.097	.110	.122	.132	45.42	39.71	34.11	28.72	23.62	EXIT	-.014
186.151	.084	-.078	.079	.079	.079	.077	.098	.112	.123	.133	44.85	39.14	33.54	28.15	23.05	EXIT	-.012
186.724	.086	-.078	.079	.079	.078	.077	.100	.113	.125	.135	44.28	38.57	32.97	27.58	22.47	EXIT	-.011
187.297	.087	-.078	.079	.078	.078	.076	.102	.115	.127	.136	43.70	37.99	32.39	27.00	21.90	EXIT	-.009
187.870	.089	-.078	.078	.078	.077	.075	.103	.117	.128	.138	43.13	37.42	31.82	26.43	21.33	EXIT	-.007
188.443	.091	-.078	.078	.078	.076	.074	.105	.118	.130	.140	42.56	36.85	31.25	25.86	20.76	EXIT	-.006
189.016	.092	-.078	.078	.077	.076	.074	.107	.120	.131	.141	41.98	36.27	30.67	25.28	20.18	EXIT	-.004
189.589	.094	-.077	.077	.076	.075	.073	.109	.122	.133	.143	41.41	35.70	30.10	24.71	19.61	EXIT	-.002
190.162	.096	-.077	.077	.076	.074	.072	.110	.123	.135	.145	40.84	35.13	29.53	24.14	19.04	EXIT	-.001
190.735	.098	-.077	.076	.075	.073	.071	.112	.125	.137	.146	40.27	34.55	28.96	23.57	18.46	EXIT	.001
191.308	.100	-.076	.076	.074	.072	.070	.114	.127	.138	.148	39.69	33.98	28.38	22.99	17.89	EXIT	.003
191.881	.102	-.076	.075	.074	.072	.069	.116	.129	.140	.150	39.12	33.41	27.81	22.42	17.32	EXIT	.005
192.454	.104	-.076	.075	.073	.071	.068	.118	.131	.142	.152	38.55	32.84	27.24	21.85	16.74	EXIT	.007
193.027	.105	-.075	.074	.072	.070	.067	.120	.133	.144	.153	37.97	32.26	26.66	21.27	16.17	EXIT	.008
193.600	.107	-.075	.073	.071	.068	.065	.122	.135	.146	.155	37.40	31.69	26.09	20.70	15.60	EXIT	.010
194.172	.109	-.074	.072	.070	.067	.064	.124	.137	.148	.157	36.83	31.12	25.52	20.13	15.03	EXIT	.012
194.745	.111	-.073	.071	.069	.066	.063	.126	.139	.150	.159	36.25	30.54	24.94	19.56	14.45	EXIT	.014
195.318	.114	-.072	.071	.068	.065	.061	.128	.141	.152	.161	35.68	29.97	24.37	18.98	13.88	EXIT	.016
195.891	.116	-.072	.070	.067	.064	.060	.130	.143	.154	.163	35.11	29.40	23.80	18.41	13.31	EXIT	.018
196.464	.118	-.071	.069	.066	.062	.059	.132	.145	.156	.165	34.54	28.83	23.23	17.84	12.73	EXIT	.019
197.037	.120	-.070	.067	.064	.061	.057	.134	.147	.158	.167	33.96	28.25	22.65	17.26	12.16	EXIT	.021

PHI		EFFICIENCY			VELOCITY RATIO	N PRIME
DEG	MU(1)	MU(2)	MU(3)	MU(4)		
147.860	.687	.465	.300	.171	1.602	0.000
148.433	.693	.473	.308	.179	1.646	4.435
149.006	.699	.481	.316	.187	1.690	4.314
149.579	.705	.489	.324	.195	1.732	4.190
150.152	.710	.497	.333	.203	1.772	4.065
150.724	.716	.505	.341	.212	1.812	3.938
151.297	.721	.512	.350	.221	1.850	3.813
151.870	.727	.520	.359	.230	1.887	3.688
152.443	.732	.528	.368	.239	1.922	3.564
153.016	.737	.536	.377	.248	1.957	3.443
153.589	.742	.544	.386	.258	1.990	3.324
154.162	.747	.551	.395	.267	2.022	3.208
154.735	.752	.559	.404	.277	2.053	3.096
155.308	.757	.567	.413	.287	2.083	2.988
155.881	.762	.574	.422	.296	2.112	2.883
156.454	.767	.581	.431	.306	2.139	2.782
157.027	.771	.589	.440	.316	2.166	2.686
157.600	.776	.596	.449	.326	2.192	2.594
182.140	.855	.752	.675	.615	.934	0.000
182.713	.856	.753	.676	.616	.952	1.803
183.286	.857	.755	.678	.618	.971	1.848
183.859	.859	.756	.679	.619	.990	1.896
184.432	.860	.758	.680	.620	1.009	1.949
185.005	.861	.759	.681	.620	1.029	2.006
185.578	.862	.760	.682	.621	1.050	2.067
186.151	.862	.761	.683	.621	1.071	2.133
186.724	.863	.762	.684	.621	1.094	2.205
187.297	.864	.762	.684	.621	1.116	2.282
187.870	.865	.763	.684	.621	1.140	2.366
188.443	.865	.763	.684	.621	1.165	2.456
189.016	.865	.764	.684	.620	1.190	2.554
189.589	.866	.764	.684	.619	1.217	2.660
190.162	.866	.764	.684	.618	1.244	2.774
190.735	.866	.764	.683	.617	1.273	2.899
191.308	.866	.764	.682	.616	1.304	3.034
191.881	.867	.763	.681	.614	1.336	3.182
192.454	.866	.763	.680	.612	1.369	3.343
193.027	.866	.762	.679	.610	1.404	3.520
193.600	.866	.761	.677	.608	1.441	3.713
194.172	.866	.760	.675	.605	1.481	3.926
194.745	.865	.759	.673	.602	1.522	4.160
195.318	.865	.758	.671	.599	1.566	4.420
195.891	.864	.756	.668	.595	1.614	4.709
196.464	.863	.754	.665	.591	1.664	5.030
197.037	.862	.752	.662	.587	1.718	5.391

APPENDIX D

COMPUTER OUTPUT FOR NOMINAL CONFIGURATION WITH A = .503 CM (.198 IN.)

A = .19800   B = .19200   C = .07840   R = .01425   ALPHA = 51.00   DELTA = 30.00

MU(1) = .100   MU(2) = .200   MU(3) = .300   MU(4) = .400

PHI DEG	AI	BI	AP MU(1)	AP MU(2)	AP MU(3)	AP MU(4)	AW MU(1)	AW MU(2)	AW MU(3)	AW MU(4)	PSIP	PSIF MU(1)	PSIF MU(2)	PSIF MU(3)	PSIF MU(4)		CI
141.691	.073	.070	.065	.059	.053	.047	.087	.101	.113	.123	89.31	83.60	78.00	72.61	67.51	ENTRANCE	-.049
142.264	.075	.070	.065	.059	.053	.047	.089	.103	.114	.125	88.74	83.03	77.43	72.04	66.93	ENTRANCE	-.049
142.837	.077	.070	.065	.060	.053	.047	.091	.105	.116	.127	88.16	82.45	76.85	71.46	66.36	ENTRANCE	-.049
143.410	.079	.070	.065	.060	.054	.047	.093	.107	.118	.129	87.59	81.88	76.28	70.89	65.79	ENTRANCE	-.049
143.983	.081	.071	.065	.060	.054	.047	.095	.109	.120	.130	87.02	81.31	75.71	70.32	65.22	ENTRANCE	-.049
144.556	.083	.071	.065	.060	.054	.048	.097	.111	.122	.132	86.44	80.73	75.13	69.74	64.64	ENTRANCE	-.048
145.129	.085	.071	.065	.060	.054	.048	.099	.113	.124	.134	85.87	80.16	74.56	69.17	64.07	ENTRANCE	-.048
145.702	.087	.071	.066	.060	.054	.048	.101	.115	.126	.136	85.30	79.59	73.99	68.60	63.50	ENTRANCE	-.048
146.275	.089	.071	.066	.060	.054	.048	.103	.117	.128	.138	84.73	79.01	73.42	68.03	62.92	ENTRANCE	-.048
146.848	.091	.071	.066	.060	.054	.048	.105	.119	.130	.140	84.15	78.44	72.84	67.45	62.35	ENTRANCE	-.048
147.421	.093	.071	.066	.060	.054	.048	.108	.121	.132	.142	83.58	77.87	72.27	66.88	61.78	ENTRANCE	-.048
147.994	.095	.071	.066	.060	.054	.048	.110	.123	.134	.144	83.01	77.30	71.70	66.31	61.21	ENTRANCE	-.047
148.567	.097	.071	.066	.061	.055	.049	.112	.125	.136	.146	82.43	76.72	71.12	65.73	60.63	ENTRANCE	-.047
149.139	.099	.071	.066	.061	.055	.049	.114	.127	.138	.148	81.86	76.15	70.55	65.16	60.06	ENTRANCE	-.047
149.712	.101	.071	.066	.061	.055	.049	.116	.129	.140	.150	81.29	75.58	69.98	64.59	59.49	ENTRANCE	-.047
150.285	.104	.072	.067	.061	.055	.049	.118	.131	.142	.152	80.71	75.00	69.40	64.02	58.91	ENTRANCE	-.046
150.858	.106	.072	.067	.061	.056	.050	.120	.133	.144	.154	80.14	74.43	68.83	63.44	58.34	ENTRANCE	-.046
151.431	.108	.072	.067	.062	.056	.050	.122	.135	.146	.155	79.57	73.86	68.26	62.87	57.77	ENTRANCE	-.046
152.004	.110	.072	.067	.062	.056	.050	.124	.137	.148	.157	79.00	73.29	67.69	62.30	57.19	ENTRANCE	-.045
152.577	.112	.072	.067	.062	.056	.050	.126	.139	.150	.159	78.42	72.71	67.11	61.72	56.62	ENTRANCE	-.045
153.150	.114	.072	.068	.062	.057	.051	.128	.141	.152	.161	77.85	72.14	66.54	61.15	56.05	ENTRANCE	-.044
153.723	.116	.073	.068	.063	.057	.051	.130	.143	.154	.163	77.28	71.57	65.97	60.58	55.48	ENTRANCE	-.044
154.296	.118	.073	.068	.063	.057	.051	.133	.145	.156	.165	76.70	70.99	65.39	60.00	54.90	ENTRANCE	-.043
154.869	.120	.073	.068	.063	.057	.052	.135	.147	.158	.167	76.13	70.42	64.82	59.43	54.33	ENTRANCE	-.043
188.309	.073	-.073	.071	.068	.065	.042	.087	.101	.113	.123	42.69	36.98	31.38	25.99	20.89	EXIT	.015
188.882	.075	-.072	.070	.068	.064	.041	.089	.103	.114	.125	42.12	36.41	30.81	25.42	20.32	EXIT	.016
189.455	.077	-.072	.069	.067	.063	.060	.091	.104	.116	.127	41.55	35.83	30.24	24.85	19.74	EXIT	.018
190.028	.079	-.071	.069	.066	.062	.059	.093	.106	.118	.128	40.97	35.26	29.66	24.27	19.17	EXIT	.019
190.601	.081	-.070	.068	.065	.061	.057	.095	.108	.120	.130	40.40	34.69	29.09	23.70	18.60	EXIT	.021
191.174	.083	-.069	.067	.064	.060	.056	.097	.110	.122	.132	39.83	34.12	28.52	23.13	18.02	EXIT	.022
191.747	.085	-.068	.066	.062	.059	.055	.099	.112	.124	.134	39.25	33.54	27.94	22.55	17.45	EXIT	.024
192.320	.087	-.068	.065	.061	.057	.053	.101	.115	.126	.136	38.68	32.97	27.37	21.98	16.88	EXIT	.025
192.893	.089	-.067	.064	.060	.056	.052	.104	.117	.128	.138	38.11	32.40	26.80	21.41	16.31	EXIT	.027
193.466	.091	-.066	.062	.059	.055	.050	.106	.119	.130	.140	37.53	31.82	26.22	20.84	15.73	EXIT	.029
194.039	.094	-.065	.061	.057	.053	.049	.108	.121	.133	.142	36.96	31.25	25.65	20.26	15.16	EXIT	.030
194.612	.096	-.063	.060	.056	.052	.047	.110	.123	.135	.144	36.39	30.68	25.08	19.69	14.59	EXIT	.032
195.185	.098	-.062	.059	.055	.050	.045	.113	.126	.137	.147	35.82	30.10	24.51	19.12	14.01	EXIT	.033
195.757	.101	-.061	.057	.053	.048	.044	.115	.128	.139	.149	35.24	29.53	23.93	18.54	13.44	EXIT	.035
196.330	.103	-.060	.056	.051	.047	.042	.117	.130	.142	.151	34.67	28.96	23.36	17.97	12.87	EXIT	.037
196.903	.106	-.058	.054	.050	.045	.040	.120	.133	.144	.154	34.10	28.39	22.79	17.40	12.30	EXIT	.038
197.476	.108	-.057	.052	.048	.043	.038	.123	.135	.147	.156	33.52	27.81	22.21	16.82	11.72	EXIT	.040
198.049	.111	-.055	.051	.046	.041	.036	.125	.138	.149	.159	32.95	27.24	21.64	16.25	11.15	EXIT	.042
198.622	.114	-.053	.049	.044	.039	.034	.128	.141	.152	.161	32.38	26.67	21.07	15.68	10.58	EXIT	.043
199.195	.117	-.052	.047	.042	.036	.031	.131	.144	.155	.164	31.80	26.09	20.49	15.11	10.00	EXIT	.045
199.768	.120	-.049	.045	.039	.034	.029	.134	.147	.158	.167	31.23	25.52	19.92	14.53	9.43	EXIT	.047

PHI DEG	EFFICIENCY MU(1)	MU(2)	MU(3)	MU(4)	VELOCITY RATIO	N PRIME
141.691	.772	.611	.490	.397	1.034	0.000
142.264	.776	.616	.496	.402	1.062	2.811
142.837	.779	.621	.501	.407	1.090	2.808
143.410	.783	.625	.506	.412	1.118	2.803
143.983	.786	.630	.511	.417	1.146	2.797
144.556	.789	.634	.516	.422	1.174	2.790
145.129	.792	.639	.520	.427	1.202	2.781
145.702	.795	.643	.525	.432	1.230	2.771
146.275	.798	.647	.530	.436	1.257	2.760
146.848	.801	.652	.535	.441	1.285	2.747
147.421	.804	.656	.540	.446	1.312	2.734
147.994	.807	.660	.544	.451	1.339	2.719
148.567	.810	.664	.549	.456	1.366	2.703
149.139	.812	.668	.554	.461	1.393	2.686
149.712	.815	.672	.558	.466	1.420	2.669
150.285	.818	.676	.563	.471	1.446	2.650
150.858	.820	.680	.568	.476	1.473	2.631
151.431	.823	.684	.572	.481	1.499	2.611
152.004	.825	.688	.577	.486	1.525	2.590
152.577	.828	.692	.582	.491	1.550	2.569
153.150	.830	.696	.586	.496	1.576	2.547
153.723	.833	.699	.591	.501	1.601	2.525
154.296	.835	.703	.595	.506	1.626	2.503
154.869	.837	.707	.600	.511	1.651	2.480
188.309	.813	.680	.581	.504	1.000	0.000
188.882	.815	.682	.583	.505	1.036	3.526
189.455	.816	.684	.584	.506	1.072	3.683
190.028	.818	.685	.585	.506	1.111	3.857
190.601	.819	.687	.586	.506	1.151	4.049
191.174	.820	.687	.586	.506	1.194	4.262
191.747	.821	.688	.586	.505	1.239	4.498
192.320	.821	.688	.586	.504	1.287	4.761
192.893	.822	.688	.585	.502	1.337	5.058
193.466	.822	.688	.583	.500	1.391	5.387
194.039	.822	.687	.582	.497	1.449	5.761
194.612	.822	.686	.580	.493	1.511	6.185
195.185	.822	.685	.577	.489	1.577	6.670
195.757	.821	.683	.573	.484	1.650	7.226
196.330	.820	.681	.569	.478	1.728	7.870
196.903	.819	.678	.564	.471	1.814	8.621
197.476	.817	.674	.558	.464	1.909	9.506
198.049	.815	.669	.552	.454	2.015	10.560
198.622	.813	.664	.544	.444	2.133	11.830
199.195	.809	.658	.534	.431	2.267	13.384
199.768	.806	.650	.523	.416	2.420	15.318

DISTRIBUTION LIST

Commander
U.S. Army Armament Research and
Development Command
ATTN: DRDAR-LCN, Col. Hyatt
F. Saxe
G. Demitrack
L. Horowitz
A. Nash
R. Brennan
B. Frey
S. Israels
C. Janow (10)
R. Nitzsche
L. Post
H. Rand
R. Shaffer
D. Taravella
G. Taylor
F. Tepper (10)
M. Wiener
L. Wisse
DRDAR-TSS (5)
Dover, NJ 07801

Commander
Harry Diamond Laboratories
ATTN: Library
DRXDO-DAB, D. Overman
Washington, DC 20436

Defense Documentation Center (2)
Cameron Station
Alexandria, VA 22314

Commander
U.S. Army Armament Materiel and
Readiness Command
ATTN: DRSAR-LEP-L
Rock Island, IL 61298

Commander
U.S. Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL (Technical Library)
White Sands Missile RAnge, NM 88002

Weapon System Concept Team/CSL
ATTN: DRDAR-ACW
Aberdeen Proving Ground, MD 21010

Technical Library
ATTN: DRDAR-CLJ-L
Aberdeen Proving Ground, MD 21005

Technical Library
ATTN: DRDAR-TSB-S
Aberdeen Proving Ground, MD 21010

Technical Library
ATTN: DRDAR-LCB-TL
Benet WCapons Laboratory
Watervliet, NY 12189

U.S. Army Materiel Systems Analysis Activity
ATTN: DRXSY-MP
Aberdeen Proving Ground, MD 21005